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Telesat Canada

STUDY OF L-BAND UTILIZATION BY MSAT
SUB-TASK 3. GROUND SEGMENT CONCEPTS AND PARAMETERS

PREPARED FOR

Department of Communications
Submitted by:
TELESAT CANADA

FINAL

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Ground Segment Concepts and Parameters

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0. INTRODUCTION

This sub-task report on the study of L-band utilization by MSAT specifies those aspects of the L-band ground segment which differ, from their UHF counterparts, due to change in the frequency of operation as well as the impact of a different service capacity and beam configuration associated with the L-band system.

The objective of this task is to provide technical and cost comparison of L-band versus UHF earth terminals such that the information together with system and space segment data can be used to generate overall system specifications and determine the most cost effective MSAT service concept.

The study of L-band as was tasked by the DOC included two major requirements. These are:

(a) Examining the potential impact of changing the frequency of operation from UHF (821-825 MHz and 866-870 MHz) to L-band (1645.5-1660.5 and 1544-1559 MHz).

(b) Examining the potential impact of adding L-band capability to the MSAT system.

To evaluate the impact of the above requirements on L-band ground segment the following topics are addressed:

(1) Types of services most suited to L-band frequency of operation and availability of L-band earth

terminals and RF components in the current commercial market.

(2) Parameters of mobile, fixed and transportable antenna systems at L-band required to compensate, partly or fully, the higher L-band transmission losses.

(3) Assessment of the current Canadian R&D work on mobile antenna systems to help identify practical (easily realizeable) antenna parameters for system trade-off analysis.

(4) Evaluation of certain DAMA parameters which might be impacted by system user capacity and beam topology specific to the L-band system.

(5) Assessment of changes in cost, for mobile terminals and DAMA system, which might occur as a result of L-band utilization.

The general framework for study of L-band utilization by MSAT, as adopted by the L-band study team, is based on the definition of three alternative plans for Canada-US cooperative systems with the reference plan being that of the Business Proposal of March 1985. Plan 1 is a system whereby each country is served by a dedicated L-band satellite. The spacecraft size is PAM-D or PAM-DII. Plan 2 is a system of one satellite per country, but each satellite has a dual band payload; UHF payload as in the reference plan with the excess resources dedicated to the L-band system. Spacecraft size is PAM-DII or larger. Plan 3 is a system whereby each country is served by 2 satellites, one a dedicated

UHF and the other a dedicated L-band satellite. The spacecraft size is PAM-D or PAM-DII.

Further, for each of the above alternative plans the study team adopted two alternative implementation scenarios to assess the impact of changing the frequency of operation. The first scenario is to compare L-band to UHF-band on an equal basis with some governing assumptions namely; a) attempt to change system parameters as little as possible such as maintaining the same overall link performance while keeping the SHF link parameters unchanged; b) keep the dimension of vehicular antennas the same as for UHF and c) preserve the satellite coverage areas as in the reference plan. As a result, only two and four-beam configurations are considered with spacecraft size and service life similar to that of corresponding UHF configurations. The second scenario is to allow certain modifications to the L-band design in order to arrive at a viable L-band system. These include reduction of fade margins and increase in service life to 10 years.

The effect of the above plans and scenarios on the direction of the ground segment study is three-fold;

(1) Analyze vehicular antenna performance while assuming the same dimension as for the UHF in order to make preliminary comparisons. However, with reference to the recent Canadian R&D on mobile antennas, designs of different size and concept are also assessed.

(2) Exclude certain types of earth terminals such as base stations, gateways, etc., from the sub-task

study, since they are under the SHF beam with the attendant assumption of SHF link performance being the same as for the reference plan.

(3) Consideration of some relevant DAMA parameters in relation to L-band beam configurations and system user capacities.

1.0 SERVICE CONCEPTS AND MOBILE TERMINAL AVAILABILITY

1.1 TYPES OF SERVICE

Services that have been identified by potential mobile satellite service providers as potential applications for L-band include the following:

- Mobile Radio Service
- Mobile Telephone Service
- Fixed or Transportable Service
- Data Service
- Paging Service
- Aeronautical Service

In addition to the above, there are other services or combination of services such as radio determination or geographical positioning service. This L-band study considers the ground segment concepts related only to mobile and transportable services. The operational assumptions remain the same as in the reference plan of the Business Proposal of March 85.

1.2 SERVICES MOST SUITED TO L-BAND

There are two unfavourable propagation aspects to the L-band frequency of operation as compared to UHF. That is, (1) a higher free space path loss which is common to both mobile and transportable services and, (2) increased propagation attenuation due to multipath and shadowing by terrain obstacles which is more significant for mobile services.

As a result, to attain comparable system availability to UHF-band operation, the system user capacity will undoubtedly be lower if the extra path loss could not be fully compensated by increases in the mobile antenna gain and/or satellite EIRP. To improve on the system capacity and the resultant user population base, transportable or portable services which exploit the advantages of higher gain directional antennas and clear line of sight could provide acceptable performance and system availability.

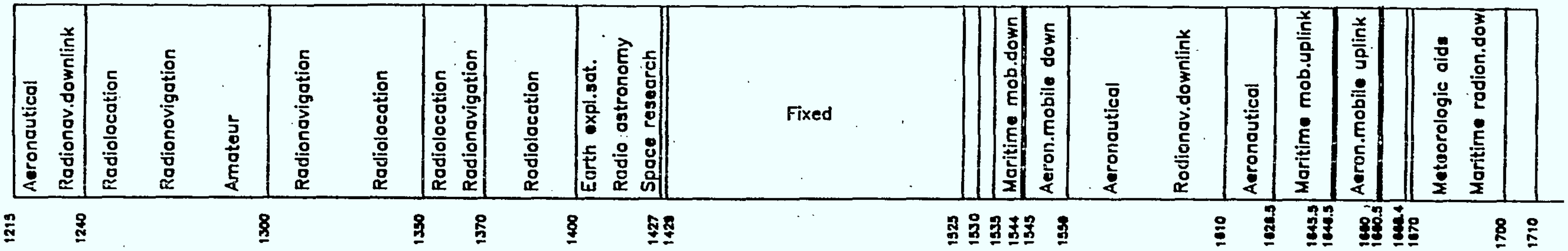
One could also consider the possibility of lowering the transmission rate of mobile terminals. For voice communications, the 2.4 kbps rate yields marginal voice quality and may not be further reduced, given current technology. One option to consider then is a low transmission rate mobile data communication service. To ensure compatibility with the 5 KHz channel separation scenario, the mobile data terminal would accept data stream from the user at a rate less than 2.4 kbps and add on forward error-correction code bits to reach a gross transmission rate of 2.4 kbps; error-correction encoding would then protect the data from adverse propagation conditions within the designed margins.

In order to determine whether these services would improve the commercial viability of an L-band or a dual-band MSAT system and thus warrant further study, one has to translate these applications into marketable classes of services and their project their relative share of the MSAT traffic mix .

1.3 AVAILABILITY OF L-BAND MOBILE TERMINALS

INMARSAT is currently the only commercial satellite system providing mobile communication at L-band, as shown in the frequency allocations of figure 1.1. Table 1.1 summarizes the parameters of the different standards of mobile earth stations presently deployed or planned to be deployed in the INMARSAT system. Standard A ship earth stations consists of a relatively high-cost, large antenna and complex stabilization/pointing system designed to provide good quality voice/data, and telex channels. Standard A is the only ship earth station currently deployed in the INMARSAT system of which, up to now, over 2500 had been considered for use. Specifications for other standards are in progress and are planned to be deployed in the second generation INMARSAT system in the late 1980. Standards B and C are forseen as ultimately the most common shipborne installation within INMARSAT system, providing LPC digital voice, telegraphy and low speed data.

Examining the parameters of the various standards of ship earth stations in table 1.1, one would observe that the Standard A specifications are for relatively large installations and are not appropriate for adoption as L-band ground terminals for the MSAT application. Comparing the parameters of the L-band MSAT mobile terminals with those of INMARSAT one would conclude that L-band specifications are somewhere between INMARSAT Standards B and C.



WARC'82 frequency plan

Figure 1.1 L-band mobile-satellite frequency allocations

STANDARD	"A"		"B"	"C"
	1st Generation	2nd Generation		
Characteristics:	23 dBic	20 dBic	15 dBic	6dBic
Aperture Size	4' diameter	3' diameter	–	–
G/T	-4 dB/K	-4 dB/K	-10 dB/K	-19 dB/K
Noise Temperature	400K	200K	–	–
EIRP Per Voice Carrier	36 dBW	36 dBW	28 dBW	18 dBW
Stabilization	Active	Passive	–	–
Service:				
Telephony	FM	–	Digital	–
Telegraphy	Telex		Telex	Telex
Low Speed Data	2400 bps		2400 bps	1000 bps
Dedicated Data	–		4800 bps	1000 bps
Implementation	Existing		1986-1988	1986-1988

Table 1.1 Existing and Potential Inmarsat Ship Earth Station Characteristics

1.4 AVAILABILITY OF L-BAND LNAs AND HPAs

There is a broad choice of LNAs available for the L-band operation, with the noise figure as low as 1 dB, various gains, package configuration and reliability classes. Since, we are dealing with low signal levels there should be no significant difference, if any, between the 0.8-0.9 GHz and 1.5-1.6 GHz LNA designs and consequently little cost difference.

There is also a broad choice of HPAs available for the L-band operation, with the output power as high as 100W, various gains, flatness, VSWR, package configuration and reliability classes. However, most of the devices are optimized for the pulsed mode of operation (avionics and radar) or Class-C continuous wave mode (communication and telemetry applications using FM or digital modulation schemes with nearly constant envelope), rather than linear, Class-A, mode which might be needed for ACSSB transmission (for MSAT applications the very high level of linearity may not be required). Further, the design of L-band power amplifiers has relatively stiffer constraints with respect to that of UHF. These constraints are due to;

(a) The good performance at high frequencies requires smaller physical dimensions of the active device which is usually silicon bi-polar transistor at UHF and L-band. But, a reduction in chip size will increase thermal resistance and thereby lower power handling capability, assuming no increase in the junction temperature is allowed to avoid reliability degradation.

(b) The final stage of the power amplifier could require high load mismatch capability to survive the accidental antenna disconnection or damage.

(c) Since the mobile terminal will be located in a car, the available power supply voltage is about 13.5V d.c., rather than 24-28V d.c. used in most of today's available L-band HPA units.

These contradictory requirements, namely low d.c. voltage versus linearity and small dimensions versus high power seems to be a limiting factor in high power devices. Therefore, the gain, flatness and bandwidth are sacrificed for efficiency. Although these constraints are not major design issues, they would, nonetheless, impose a relatively higher cost for L-band HPAs than for the UHF. The cost aspects are addressed in Section 5 of this report.

Referring to the other RF sub-systems of the mobile terminal, the antenna is the most critical element and therefore it is addressed both in Section 2 and 3 of this report. Section 2 basically considers the antenna transmit gain and receive G/T performance at L-band to provide data for system analysis. Section 3, by referring to the recent Canadian R&D on mobile antennas, assesses the issue from a more practical point of view.

2. L-BAND GROUND SEGMENT ANTENNAS

2.1 INTRODUCTION

This section addresses the impact of changing the frequency of operation from UHF to L-band on two distinct classses of antennas namely, mobile and stationary types. For the mobile antennas, first the impact of using an L-band omni-directional antenna is discussed and then the desired characteristics of a steerable phased array antenna is given. The framework for analyzing the latter class of antenna has been the assumption to maintain the dimension of the L-band vehicular antenna the same as for UHF.

For the L-band stationary class of antennas, fixed, transportable and portable types are discussed. The framework of analysis is the assumption that they should have broad enough beamwidth in both elevation and azimuth planes so that alignment is not too critical and that the antenna would be suitable both in size and weight as well as easily erectable.

2.2 L-BAND MOBILE ANTENNAS

2.2.1 OMNI - DIRECTIONAL ANTENNAS

Assume that it is feasible to design a simple single element azimuthally omni-directional antenna with a minimum directivity of 10 dBic. A minimum directive gain of 10 dBic is required since there is 5 dB difference in free space loss between L-band and UHF downlink frequencies. If we assume that there would be only 1 dB network loss due to the duplexer, and ignoring the additional propagation loss at L-band over UHF-band, the mobile terminal would have the same performance as in the UHF when satellite EIRPs per carrier in the two cases are identical.

The beamwidth of the antenna could be determined from:

$$G_D = K/\phi_\theta \phi_\phi$$

where G_D is the peak directivity of the antenna, K is a constant, and ϕ_θ and ϕ_ϕ are the 3 dB beamwidths in elevation and azimuth planes, respectively. For an omni-directional antenna $\phi_\phi = 360°$. In addition, we assume that $K \simeq 30,000$. Substituting these values in the above equation results in $\phi_\phi \simeq 8°$. Note that this value of 3 dB beamwidth in elevation could result in a significant amount of antenna pointing loss. Even a vehicle tilt of ±2° from the zenith due to road condition (i.e. road slope less than 4%) could cause as much as 1 dB pointing loss. Note also that the same omni-directional antenna design might not be possible to use everywhere in Canada due to excessive pointing loss caused by change of elevation angle.

From the above discussion it is clear that a simple omni-directional antenna could not be used in L-band if the traffic capacity and the satellite EIRP per carrier are to remain the same as in UHF.

It is worth mentioning that it could be possible to employ a non-steerable L-band antenna with pseudo omni-directional characteristics if a circular (or polygon) array is designed with each element(s) of the array covering only a sector of the space. The number of the elements in the array depends on the choice of the 3 dB beamwidth in elevation and the gain variation in azimuth. Table 2.1 shows the probable number of elements in the array for different values of 3 dB beamwidth in elevation plane when the maximum gain ripple in azimuth is limited to about 2 dB.

2.2.2 ARRAY ANTENNAS

The relationship between antenna directive gain, G_D, and its half power beam width is given by:

$$G_D = 4\pi \eta A/\lambda^2 \simeq K/\phi_o^2$$

where the factor K can vary slightly for different classes of antennas and for high efficiency antennas is $\simeq 4 \times 10^4$. λ is the wavelength of the RF signal, A is the array area, and η is the antenna efficiency and it is assumed that the antenna has identical 3 dB beamwidth in azimuth and elevation planes. The antenna directive gain at L-band (1550 MHz) for an aperture of 70cm x 70cm (the same physical size as the one assumed for UHF operation) is about 21.2 dBi when an aperture efficiency of 80% is assumed.

To avoid the formation of grating lobes when the beam is steered, the spacing between individual antenna element

3 dB BW in Elevation (deg.)	3 dB BW in Azimuth (deg.)	No. of Elements
40	47	9
30	63	7
25	75.7	6
20	95	5

Table 2.1: Number of elements in a circular array for an omni-directional coverage. The gain ripple in azimuth is limited to 2 dB.

3 dB, BW°	1 dB BW°	Directive gain(dBic)	Number of Elements in array
10	2.9	26	100
15.5	4.3	22	45
17.4	5	21	35
20	5.8	20	25
25	7.2	18	16
30.4	8.6	16	11
35.1	10.1	15	8
40.9	11.5	13	6

Table 2.2: Required number of elements in an L-band phased array antenna for different antenna beamwidths.

in the array cannot significantly exceed a half wavelengths. With such spacing, the number of array elements, N, is given by:

$$N = 4Lx \cdot Ly/\lambda^2$$

where Lx and Ly are the aperture dimension. For a square array, the number of array elements becomes:

$$N = 4L^2/\lambda^2 \simeq 10^4/\phi_o^2 .$$

Table 2.2 shows the required number of array elements for different antenna beamwidths, as well as their respective 1 dB beamwidths. Note that the number of elements increases as the directive gain increases and would be at least 35-40 elements for an L-band antenna with an aperture size of 70 cm x 70 cm. Table 2.3 lists the desired characteristics of such an antenna and its expected power gain.

Table 2.4 gives the noise budget and overall G/T of the phased array antenna. Further, for ease of reference, Table 2.5 summerizes some of the UHF and L-band mobile terminal parameters.

Parameters	Values
Total aperture area	70cm x 70cm
Frequency Range	1544 MHz to 1660.5 MHz
Directivity	21.2 dBic (Rx), 22.2 dBic (Tx)
Scan Loss[1]	4 dB
Feeder Loss	1 dB
Loss of Phase Shifters[2]	2.5 dB
Duplexer Loss	1 dB
Polarization Loss	1.1 dB
Return Loss	0.2 dB
Pointing Loss[3]	1 dB
Total loss	10.8 dB
Rx gain	10.4 dBic

Table 2.3: Expected characteristics of an L-band steerable phased array antenna for mobile application.

Notes:

1. Loss due to beam scanning down to elevation angle of about 20°.

2. It could be a conservative value by as much as .8-1 dB.

3. Corresponding to 5° of pointing error due to a four-bit phase shifter.

Parameters	Values
LNA noise temperature (NF = 2 dB)	170 K
Antenna noise temperature	150 K
Noise temperature due to losses	210 K
Total noise temperature	421 K
Antenna gain	11.3 dBic
G/T	-15.8 dB/K

Table 2.4: Noise budget and G/T of an L-band phased array antenna for mobile application.

Parameters	UHF	L-BAND
Transmit gain, dBic	7.5	11.4
Receive gain, dBic	8.0	10.4
Transmit EIRP per carrier, dBw	11.0	23.0
LNA noise figure, dB	2.0	2.0
Receiver G/T, dB/K	-19.1	-15.8

Table 2.5: Some of the UHF and L-band mobile terminal parameters.

2.2.3 COMPARISON

It is shown that a simple azimuthally omni-directional antenna with a higher directive gain, to compensate for the increase in free space loss between UHF and L-band downlink frequencies, would result in a narrow beamwidth with a large pointing loss that renders them impractical. The alternative is to keep the gain at nominal UHF levels with the penalty of an increase in the satellite EIRP per carrier.

For the steerable phased array antenna, assuming identical 3 dB beamwidths in azimuth and elevation planes, circular polarization and same physical size as its UHF counterpart, the calculated G/T and transmit gains are -15.8 dB/K and 11.4 dBic respectively.

The G/T of -15.8 dB/K gives only an improvement of about 3.3 dB over its UHF counterpart. Since the downlink free space loss at L-band is 5 dB greater than UHF, there would be a deficit of about 1.7 dB which should be compensated by increase in the satellite EIRP per carrier for the same availability as in the UHF. This is based only on free space loss consideration and ignores the additional propagation loss at L-band which appears to be about 4.1 dB (see Sub-Task 1 report: System Concept Analysis and Comparison) bringing the total downlink deficit to about 5.8 dB.

The transmit gain of 11.4 dBic gives an improvement of about 3.9 dB compared to its UHF counterpart. However, there is a 6 dB increase in the free space loss between UHF and L-band uplink frequencies. Further, there seems to be requirement for another 6 dB increase in the

L-band uplink thermal carrier to noise power ratio to compensate for propagation attenuation at L-band for specific availability considerations (see Sub-Task 1 report: System Concepts Analysis and Comparison). This implies that the HPA output power of the mobile terminal would be about 14.8w.

Note that the number of elements in an L-band phased array antenna is 3 to 4 times greater than that of UHF array and, therefore, the associated cost is expected to be higher. The cost impact is addressed in section 5.

2.3. L-BAND STATIONARY ANTENNAS

The following sub-sections discuss various types of fixed, transportable and field portable antennas in L-band with an additional gain to compensate for the differential free space loss between UHF and L-band. These antennas, while providing gain improvements should also have broad enough beamwidths in both elevation and azimuth planes so that the antenna alignment is not too critical as well as easily erectable.

2.3.1 FIXED ANTENNAS

Fixed antennas can be considered as permanent stations anywhere in Canada with a minimum elevation angle of about 10°. The antennas suitable for this purpose are helix, crossed dipole Yagi array, horn antenna, parabolic reflector, short backfire, and microstrip array.

A. HELIX ANTENNA

When operating in the axial mode, the helix antenna performs as an end fire antenna generating circularly polarized waves, with a low axial ratio across a wide bandwidth. The axial mode can easily be excited by a coaxial line and a ground plane arrangement. The helix circumference should be in the order of one wavelength.

The antenna may be ruggedly constructed, the helical conductor as integrated into a surrounding cylindrical housing which completely seals the unit from the effects of weather and also provides the necessary strength properties. The cylindrical housing offers low wind loading, and in addition offers a high dielectric constant to possible snow or ice. Ice formation occurs on the dielectric rather than on the conductor, thus minimizing its effect upon the antenna performance. The net weight of the antenna system, including the ground plane and cylindrical housing, will be about 5 kg with length of about 1 m and diameter of the ground plane less than 20 cm. The ground plane may be made of a number of radials and concentric conductors in order to reduce the wind drag.

B. CROSS DIPOLE YAGI ARRAY

A Yagi array of crossed dipoles which consists of parasitic directors and a reflecting element can provide a gain of about 16-18 dBi over both transmit and receive bands. The size and spacing of the reflector element can be used to achieve a low VSWR. The total length and cross sectional diameter of the antenna are less than 1 m and 10 cm, respectively.

The cross dipole Yagi array is slightly more complex than a helix to manufacture and the weight is also expected to be greater. The advantage that this antenna has over a helix is its ability to operate with both hands of circular polarization.

C. HORN ANTENNA

A proper design of horn can provide the desired gain in both transmit and receive bands. The aperture dimensions would be about 60 cm x 60 cm. Circular polarization could be achieved in a few ways: meander line in the aperture of horn; placing a circular polarizing element in the exciting wave-guide; using two probes in wave guide placed at right angles.

D. PARABOLIC REFLECTOR

A parabolic reflector with a circularly polarized feed, such as a crossed dipole, could be used for a fixed station. The diameter of the reflector would be about 75 cm. However, the reflector weight, wind loading and the associated cost are its disadvantages.

E. MICROSTRIP ANTENNA ARRAYS

Microstrip antennas are ideally suited for conformal arrays. They have been designed from several different kinds of elements, such as rectangular or circular disk elements.

Microstrip transmission line circuits provide phase control and power distribution to the array elements. The key features of a microstrip array are relative ease of construction, light weight, low cost, and very thin protrusion from the mounting surface.

In case of no scanning capability requirement, the diameter of the array is expected to be about 60 cm to provide the desired gain.

2.3.2 TRANSPORTABLE ANTENNAS

These are similar to fixed antennas, except for the fact that they should be transportable. That is, the antenna has to be easy to dismantle, and it should be deployable in short period of time. The antennas discussed for fixed application are all suitable for this purpose, except for parabolic reflectors.

2.3.3 PORTABLE ANTENNAS

The portable antenna should be small in volume when packaged, and light in weight so that a person could easily carry and deploy it. A collapsable helix which can be folded to minimize the size, crossed dipole Yagi, microstrip array, as well as a helix antenna are good candidate for this application. In the crossed dipole Yagi array case, the boom of the array can be kept in one piece and the crossed dipole elements may be folded over the boom for ease of carrying by a person on foot. The boom can be designed so as to minimize the wind drag (open frame). The antenna mast should be a fiberglass rod, which on one side is attached to the antenna boom and on the other side to a tripod. The total weight of the antenna would probably be less than 2 kg. It is also possible to design a light weight helix with a small ground plane suitable for this application.

2.3.4 COMPARISON

There seems to be no problem to design fixed, transportable, or field portable antennas with the required characteristics. A helix seems to be the right candidate for all three applications, and microstrip arrays are especially the best choice for suitcase type of antennas for portable application. Table 2.6 summarizes some of the expected electrical characteristics of these antennas. Table 2.7 provides noise budget and G/T. Note that antenna noise temperature budget given in Table 2.7 is for 5° elevation angle and would be reduced to about 20K for elevation angles greater than 20°. That is, G/T of -6.9 dB/K at 5° elevation would be increased to -5.9 dB/K, an improvement of 1.0 dB.

Parameters	Value
Gain	Tx:17.5 dBic Rx:19 dBic
Polarization	RHC
Axial Ratio	≃2 dB
Impedance	50 Ω
Alignment	Elev.[1]: 5°-90° Az: 0°-360°

Table 2.6: Summary of expected electrical characteristics for L-band fixed, transportable and portable antennas.

Note:

(1) For fixed antennas the minimum elevation is about 10°.

Parameters	Values
LNA Noise Temperature (NF = 2 dB)	170 K
Antenna Noise Temperature (at about 5° elevation)	100 K
Noise Temperature due to 1 dB Receiving Circuit loss	60 K
Total Noise Temperature	310 K
Antenna Receive Gain	18 dBic
G/T[1]	-6.9 dB/K

Table 2.7: Noise budget and G/T of L-band fixed or transportable antennas

(1) Note that the value of G/T given here is different from what has been used in Sub-Task 1 report. In Sub-Task 1 G/T value used is the same as that in CVS to make a just comparison. However the total noise budget used here seems reasonable since man made noise is negligible in the areas where transportable antennas are expected to be used.

3. CURRENT CANADIAN R&D ON MOBILE ANTENNA SYSTEMS

3.1 Introduction

This section assesses the current Canadian R & D activities on vehicular mobile antenna systems to help identify practical (easily realizable) antenna parameters for system trade-off analysis. Three activities in this area have been in progress in Canada. The first is by CRC who experimentally demonstrated a design of a linearly polarized adaptive array antenna with single monopole excitiation and parasitic concentric rings of passive rods as the reflecting elements. The second is by Canadian Marconi, who has a theoretical design of a circularly polarized phased array consisting of a ring of simultaneously excited drooping dipoles with one of the elements at the center. The third one is by ComDev who has a theoretical design of a mechanically rotatable antenna with a helix or crossed Yagi antenna as the radiating element. Detailed assessment of these different design approaches is the subject of the following sub-sections.

3.2 CRC'S DESIGN

On August 8, 1985, R. Milne made a presentation at CRC, Shirley Bay, on CRC's in-house R & D work on the design of adaptive array antennas for mobile communications. He introduced his patent pending linearly polarized antenna which basically consists of three parasitic concentric rings of vertical rods, of quarter wavelengths in size, where each rod would be connected to a ground plane via a pin diode, figures 3.1 and 3.2. The ring arrays can be excited by a quarter wave length monopole located at the centre of the rings. The diameter of the rings are roughly about one, one and half and two wavelengths, respectively. The size of the ground plane appeared to be about two and a half wave lengths. That is, the dimension of the antenna in L-band is approximately 50 cm in diameter and 5 cm in height, an acceptable size for passenger cars application.

When the pin diodes are in the conducting mode, the rods will act like parasitic quarter wave lengths monopoles and, therefore, reradiate the intercepted energy from the driving monople located at the centre, figure 3.3. With the diodes in non-conducting mode, the associated rods are separated from the ground plane and are virtually transparent to the incident energy. The radiation properties of the antenna strongly depends on the number and location of the parasitic monopoles in the array. That is, by applying the appropriate bias voltages to the diodes, the radiation pattern of the array could scan in both azimuth and elevation planes.

The antenna has been designed to provide either a high beam or a low beam[1]; the high beam is applicable to the US with the peak gain at about 55° of elevation, whereas the peak gain of low beam occurs at about 30° of elevation which is suited for the Canadian range of elevation angle, figures 3.4 and 3.5. When the type of beam is selected, the antenna will scan only in azimuth, and hence the pattern roll-off is used for elevation angles in the range of 20° to 35°.

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[1] Note that the two and a half wavelength diminsion refers to the design which is applicable to both Canadian and US requirements. A design which is suited to only Canadian applications is about one wavelength in diameter.

The peak gain of the low beam of this vertically polarized antenna is 11.7 dBi table 3.1. That is the low beam can provide equivalent to about 8 dBic when the 3dB loss due to polarization change from linear to circular as well as the duplexer loss are taken into consideration. Theoretically, doubling the diameter of the array could only increase the gain by about 3 dB. However, not more than 2 dB can be achieved in practice (based on informal discussion with R. Milne).

The antenna is simple in structure with proven design, looks rugged and its cost is expected to be lower with respect to the circularly polarized phased array design.

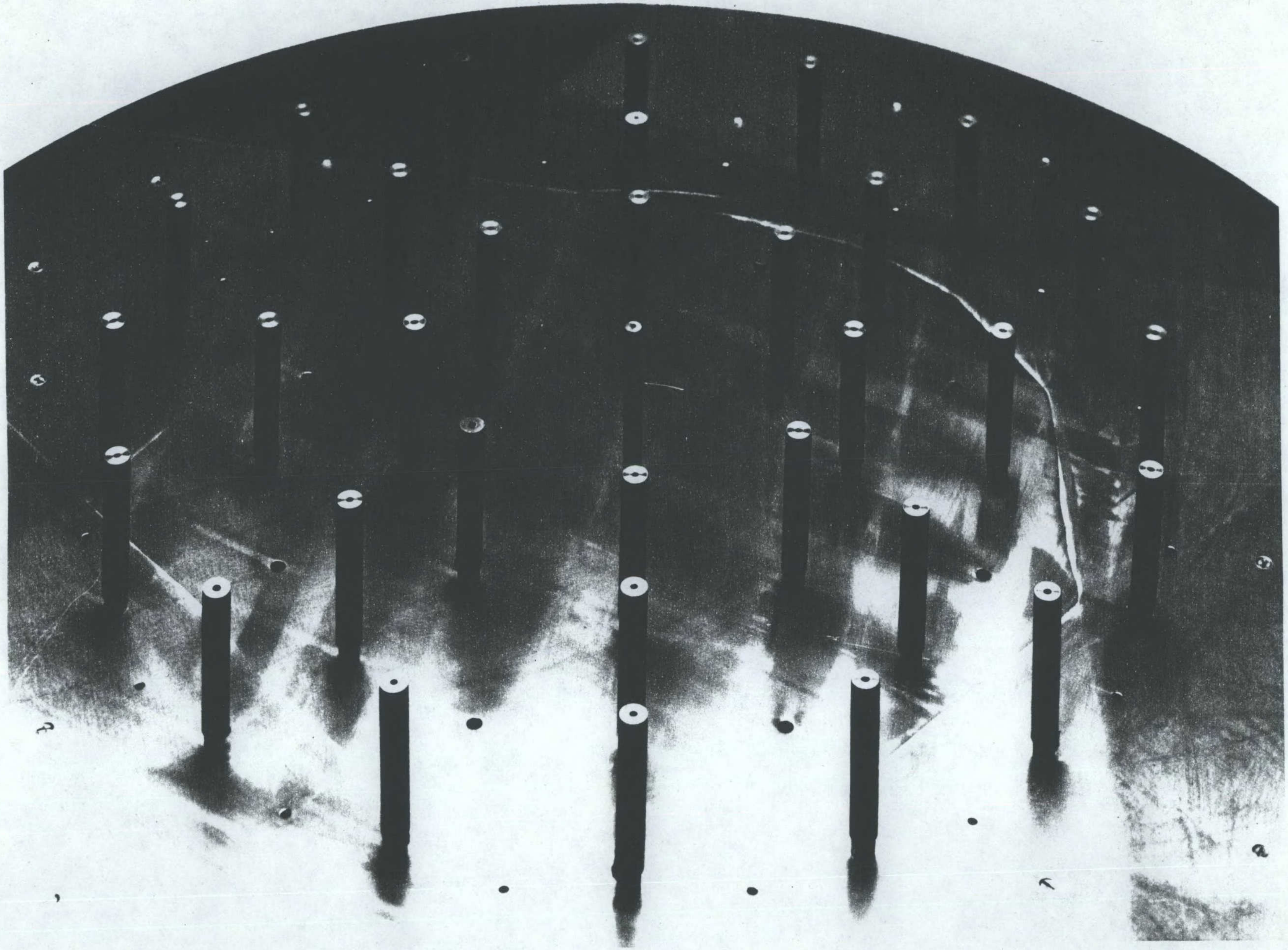
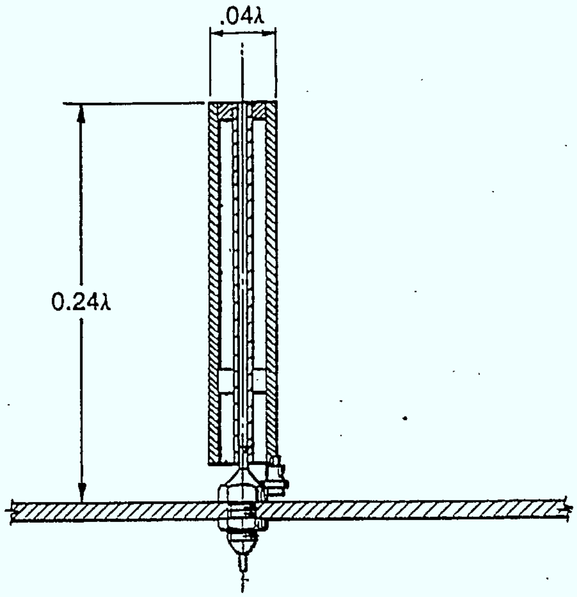
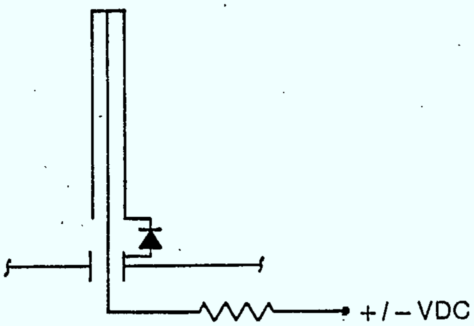


FIGURE 3.1 CRC's MOBILE VEHICULAR ANTENNA PHYSICAL STRUCTURE

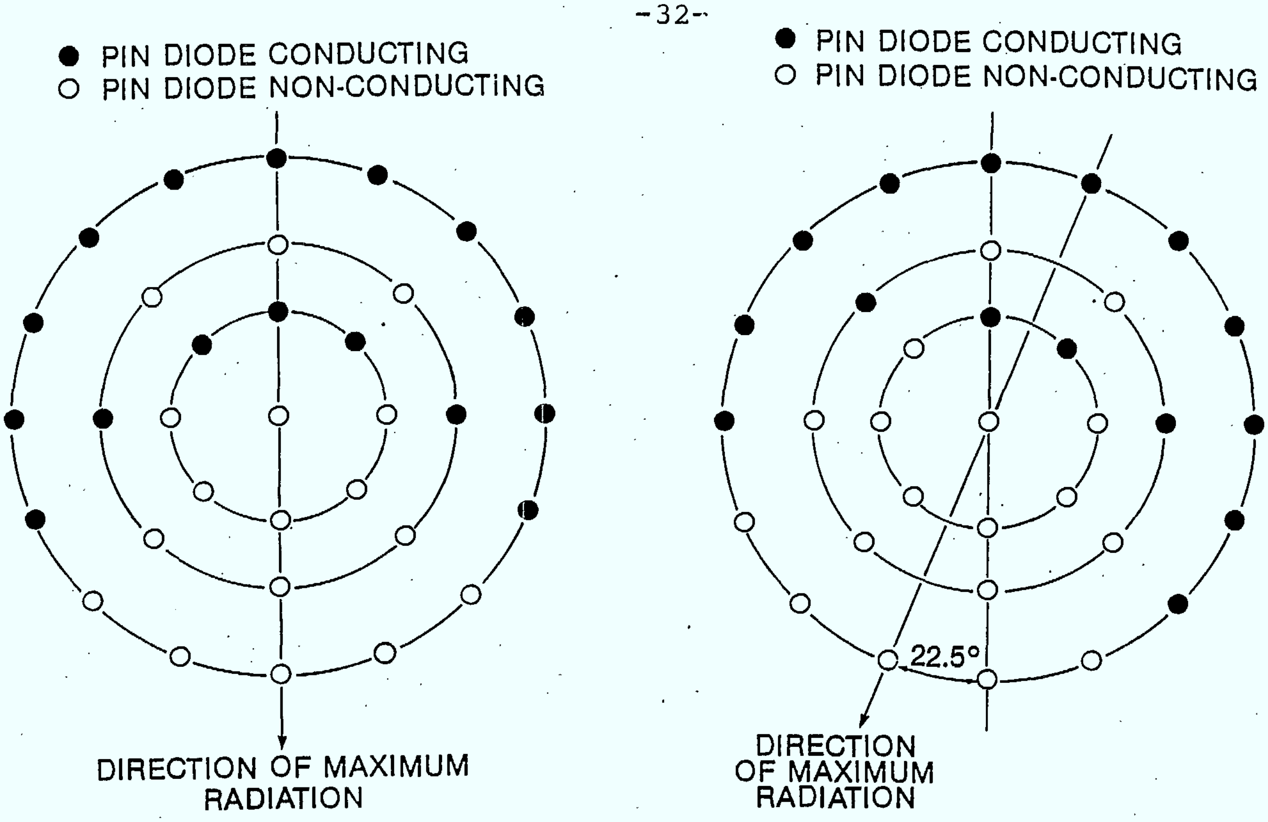


PARASITIC ELEMENT



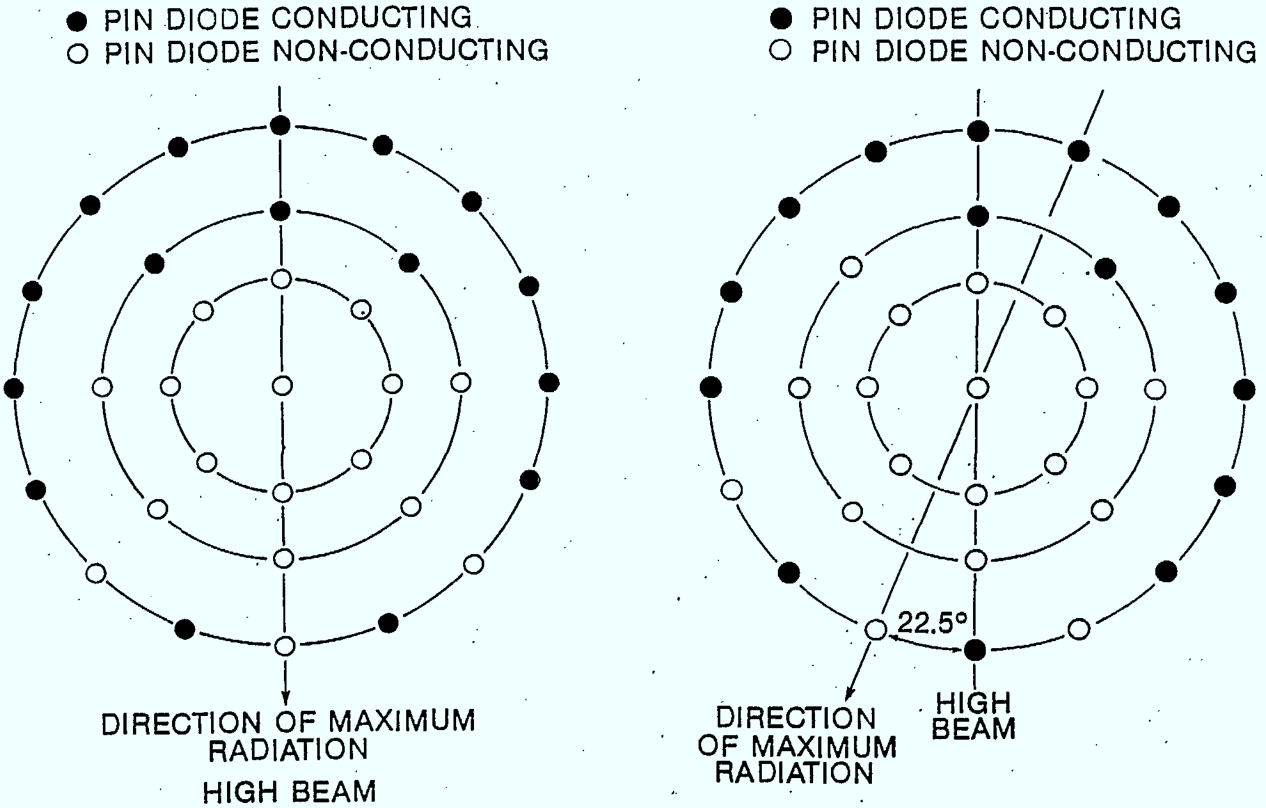
EQUIVALENT CIRCUIT

Figure 3.2 CRC's mobile vehicular antenna element



LOW BEAM

LOW BEAM



HIGH BEAM

Figure 3.3 CRC's mobile vehicular antenna parasitic ring configuration

Note: The center element is the driven one.

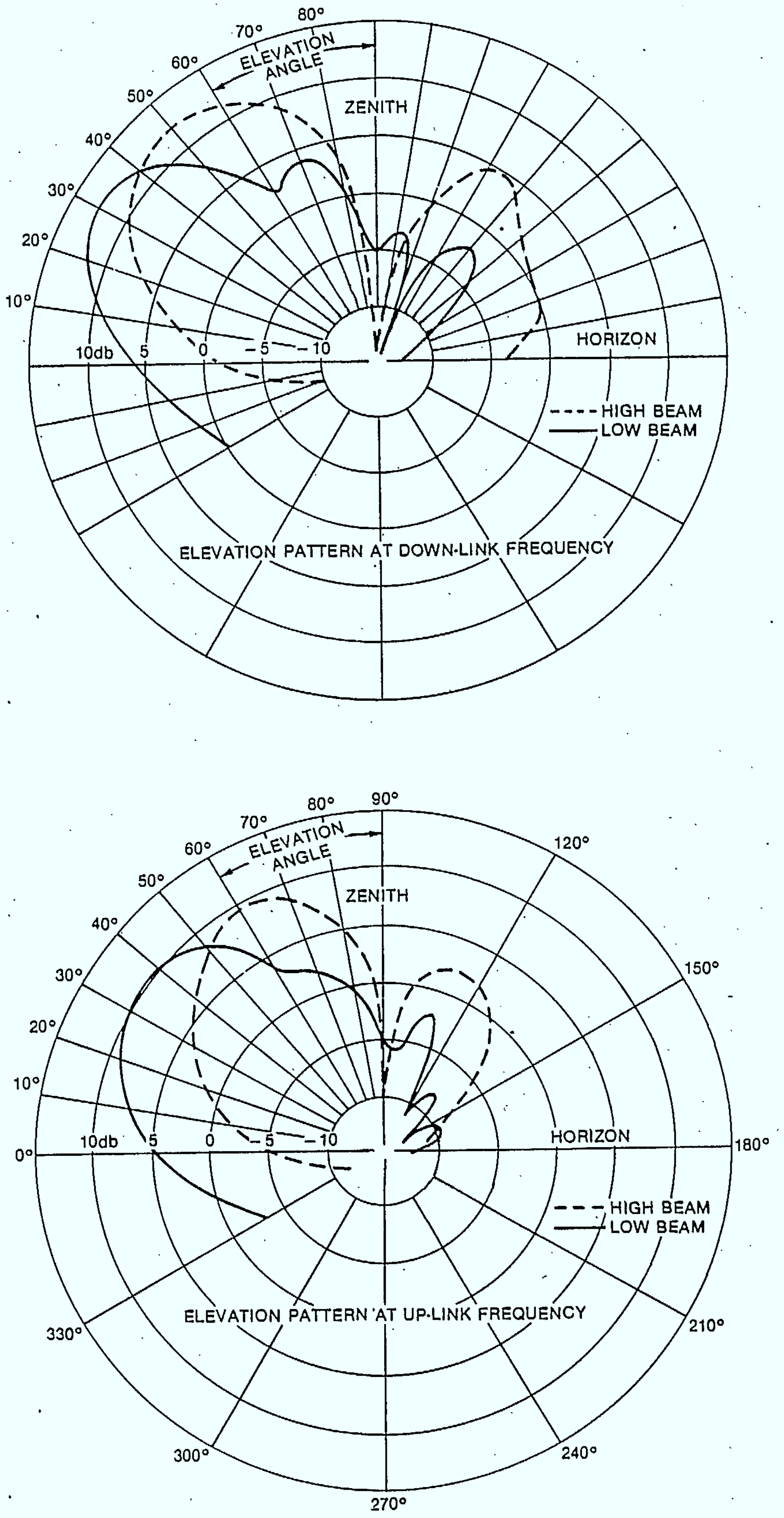
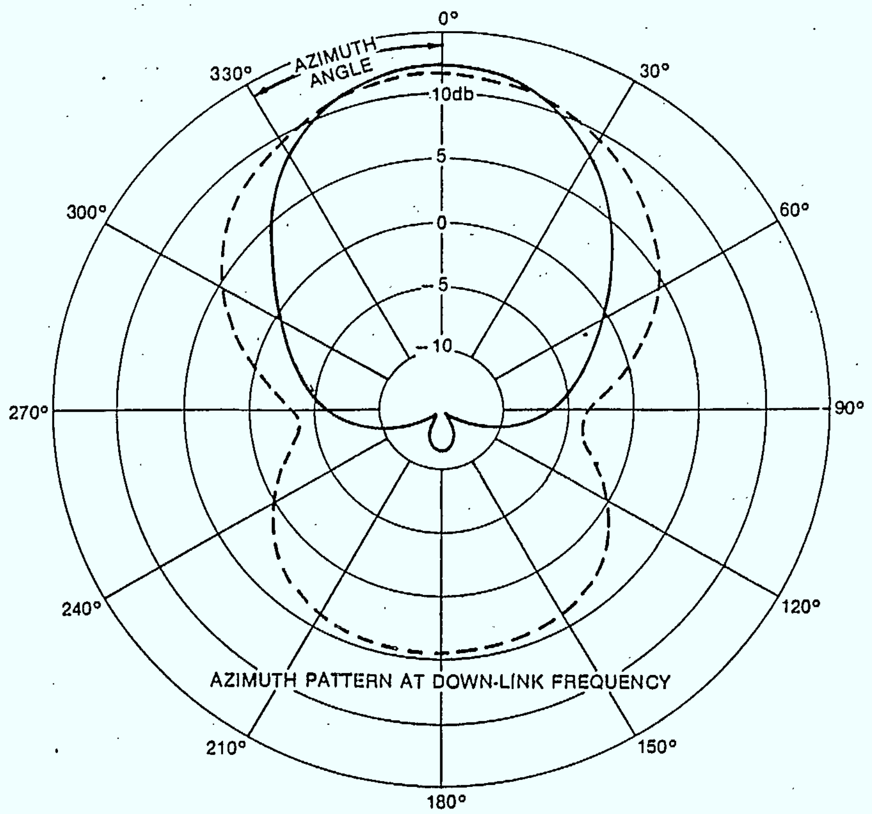


Figure 3.4 CRC's mobile vehicular antenna elevation patterns



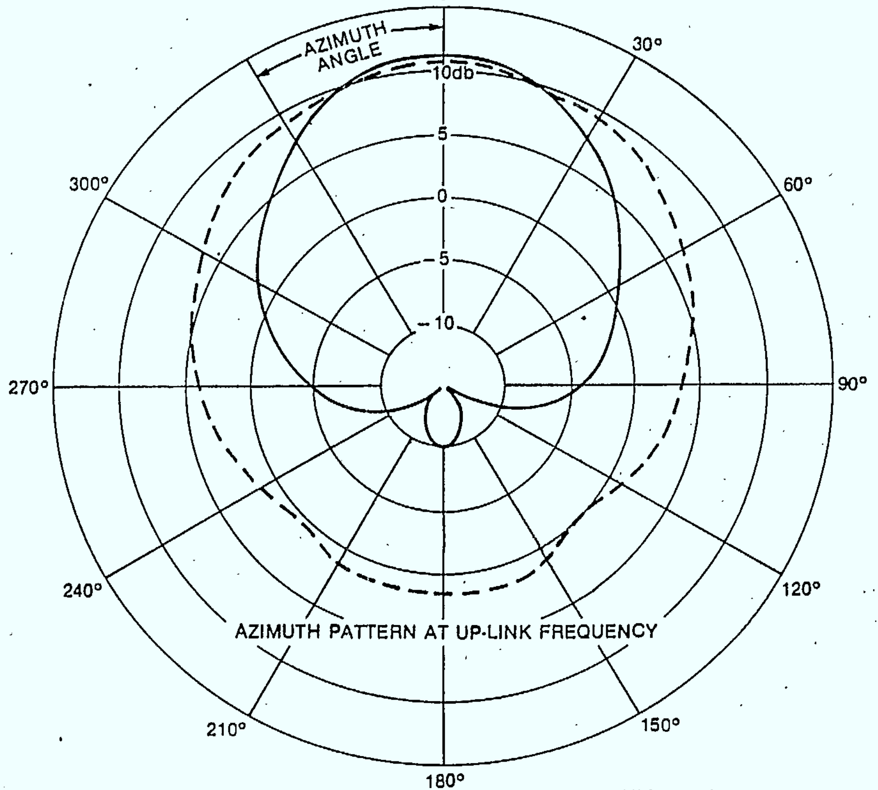


Figure 3.5 CRC's mobile vehicular antenna azimuth patterns

MEASURED LINEARLY POLARIZED ANTENNA GAINS

ELEVATION ANGLE (°)	LOW BEAM GAIN (dbi)	HIGH BEAM GAIN (dbi)
0	5.9	−5.2
5	7.3	−2.7
10	8.8	−0.4
15	9.8	1.4
20	10.8	3.3
25	11.5	4.6
30	11.7	6.6
35	11.6	8.4
40	10.9	9.8
45	9.8	10.8
50	7.3	11.1
55	4.0	11.2
60	2.2	10.8
65	3.2	10.0
70	3.8	8.5

Table 3.1 CRC's mobile vehicular antenna measured gains

3.3 MARCONI'S DESIGN

On August 23, 1985, Canadian Marconi made a presentation at CRC, Shirley's Bay to reveal their design approach on MSAT vehicle antennas. Their UHF design was a ring array consisting of seven drooping dipoles, six of which were on a circle of about one wavelength in diameter, seventh element located at the centre of the circle, figure 3.6. Because each element radiates a conical beam with a peak at an angle depending on the antenna design, an elevation scan is not necessary, and therefore, beam scanning is only required in the azimuth plane, figure 3.7. The dimension of the array with the protecting radome is about 47 cm in the base and 18 cm in height. The array radiates circular polarization and its radiation patterns in both elevation and azimuth planes at 868 MHz are given in figures 3.8 and 3.9, respectively. The maximum directivity of the array is 12.8 dBic which occurs at elevation angle of about 30 to 35° degrees. The pattern roll off loss from the peak directivity to 20° of elevation is apparently about 0.8 to 1 dB. The 3 dB beamwidth in azimuth seems to be about 60°. The Marconi's gain assessment table (Table 3.2) shows that the antenna is capable of providing better than 8 dBic gain for 20 to 35° of elevation.

The beam forming network of the UHF array should be simple since only seven elements are utilized. Marconi is proposing a 3-bit phase shifter for outer elements and a one bit phase shifter (22.5°) for the central element. Therefore, a total of nineteen pin diodes would be required. The presentation by Marconi was based on theoretical studies. The provided numerical results were a radiation pattern at only one frequency (i.e. 868 MHz). There is uncertainity about the array performance across the band. In addition, it is believed that the input impedance of the array is very sensitive to frequency, and the mutual coupling between the elements would cause a challenge to the antenna designer. The L-band design of the antenna array would need more elements if a higher gain than that of the UHF design is desired, that is, the input impedance of the array becomes even a more serious problem. Further, Marconi states that the axial ratio of the antenna is about 4 dB. That gives the cross-polarization discrimination of about 13 dB, which would be a limiting factor if polarization diversity is employed in the next generation of MSAT.

Marconi's design is as yet at a theoritical stage, however, its size, simplicity, high gain, gives the design a good potential to become a leading candidate for use on road vehicles if it can fullfill promises given in their presentation.

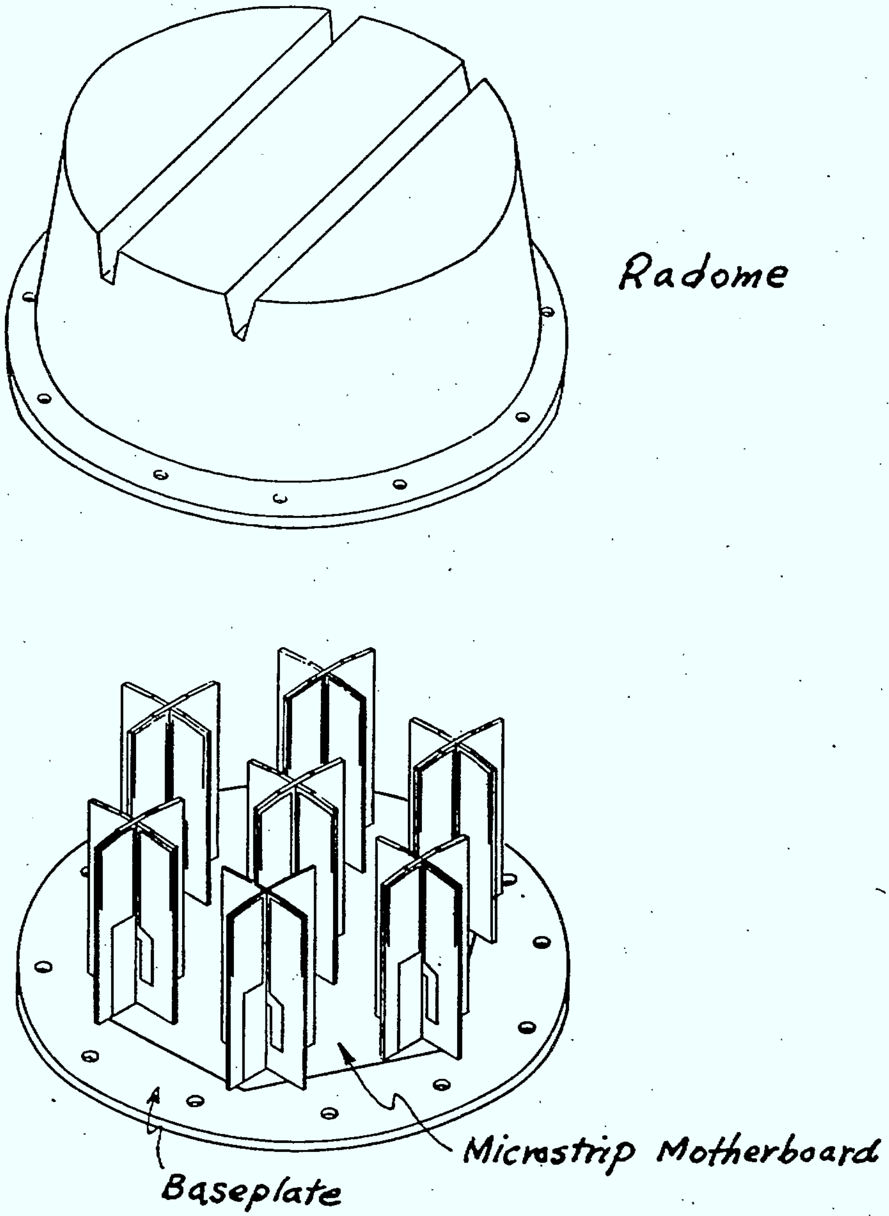


Figure 3.6 Canadian Marconi's mobile vehicular antenna physical structure

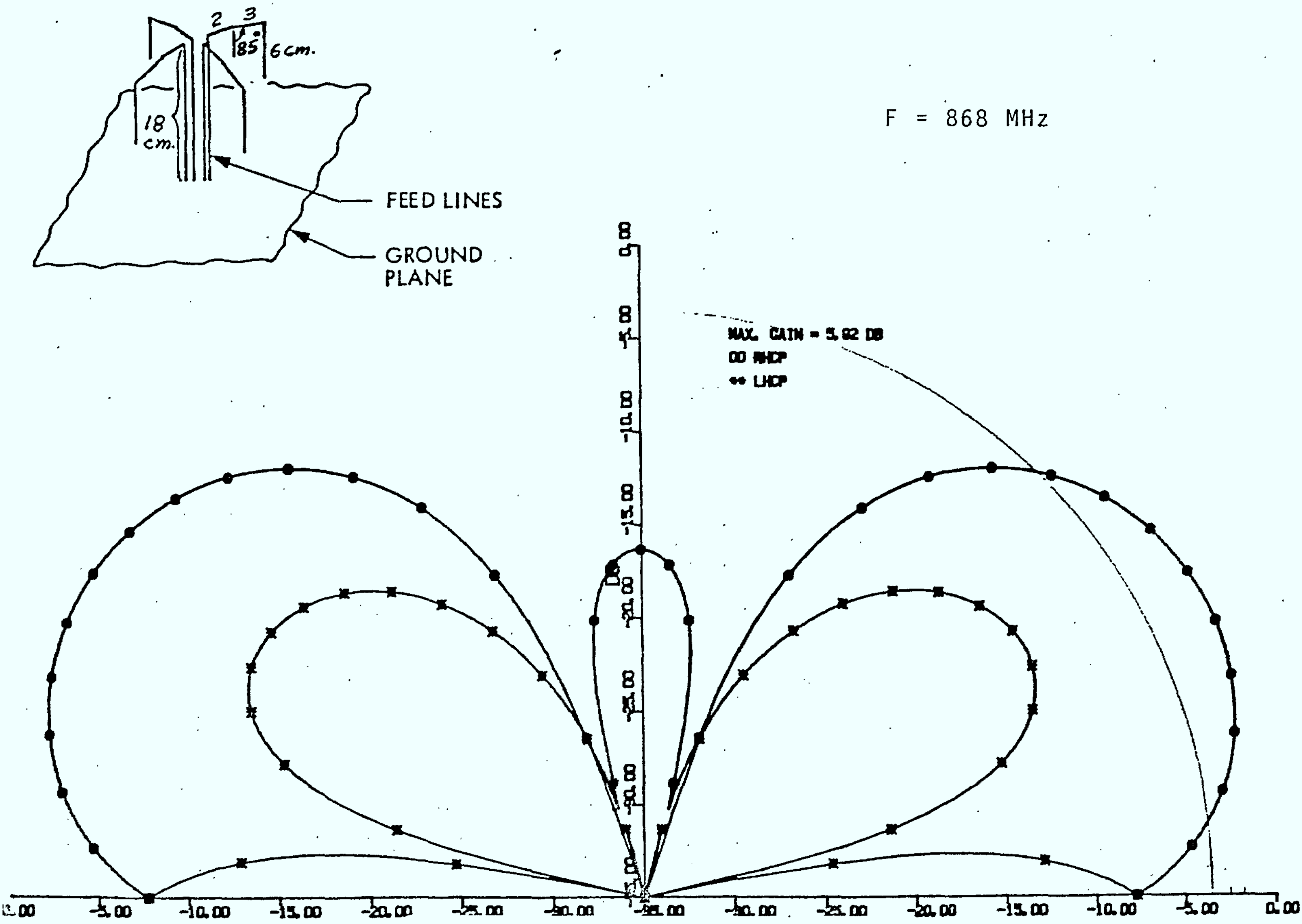


Figure 3.7 Canadian Marconi's mobile vehicular antenna elevation pattern for a single element

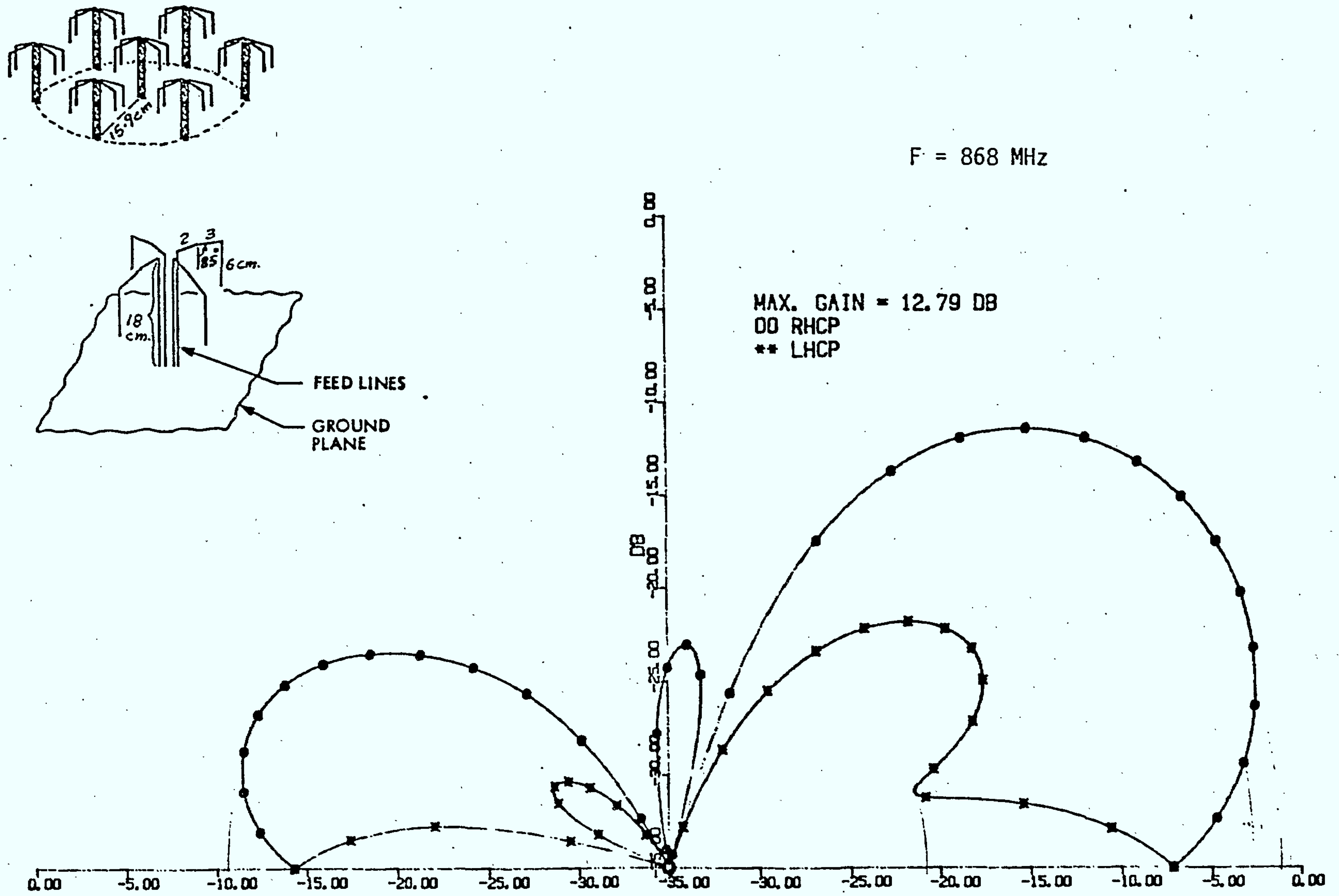
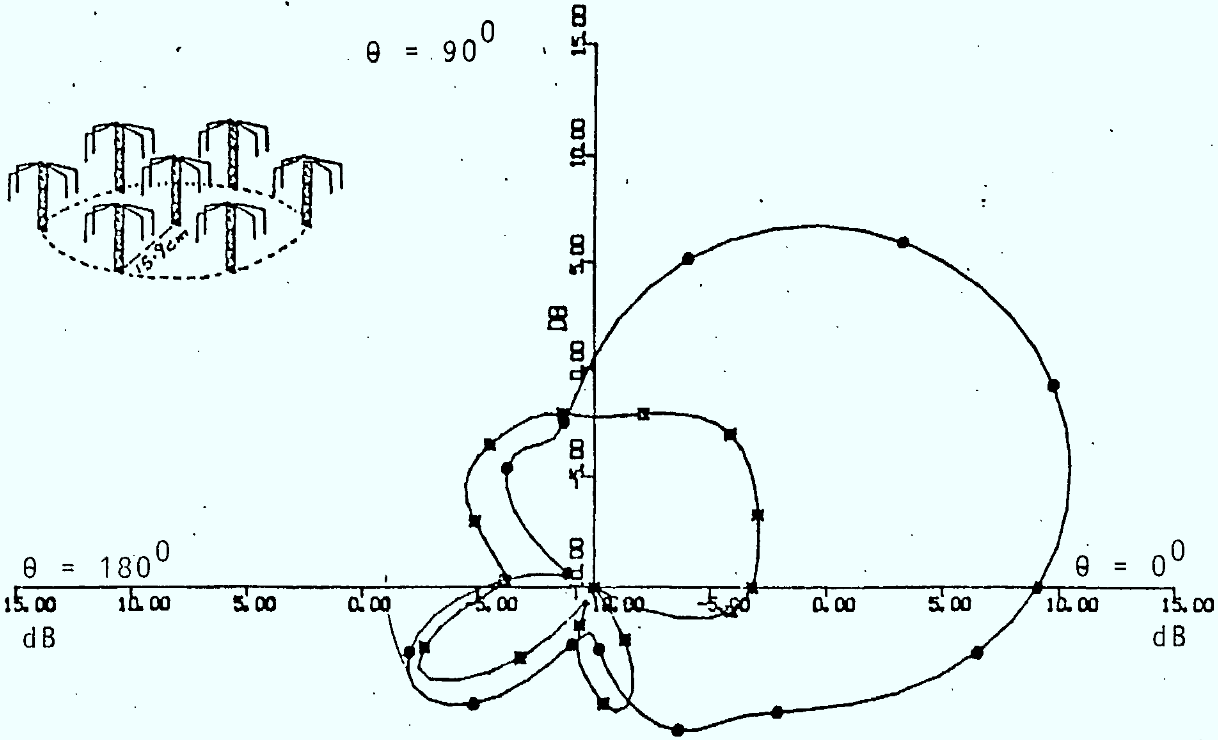
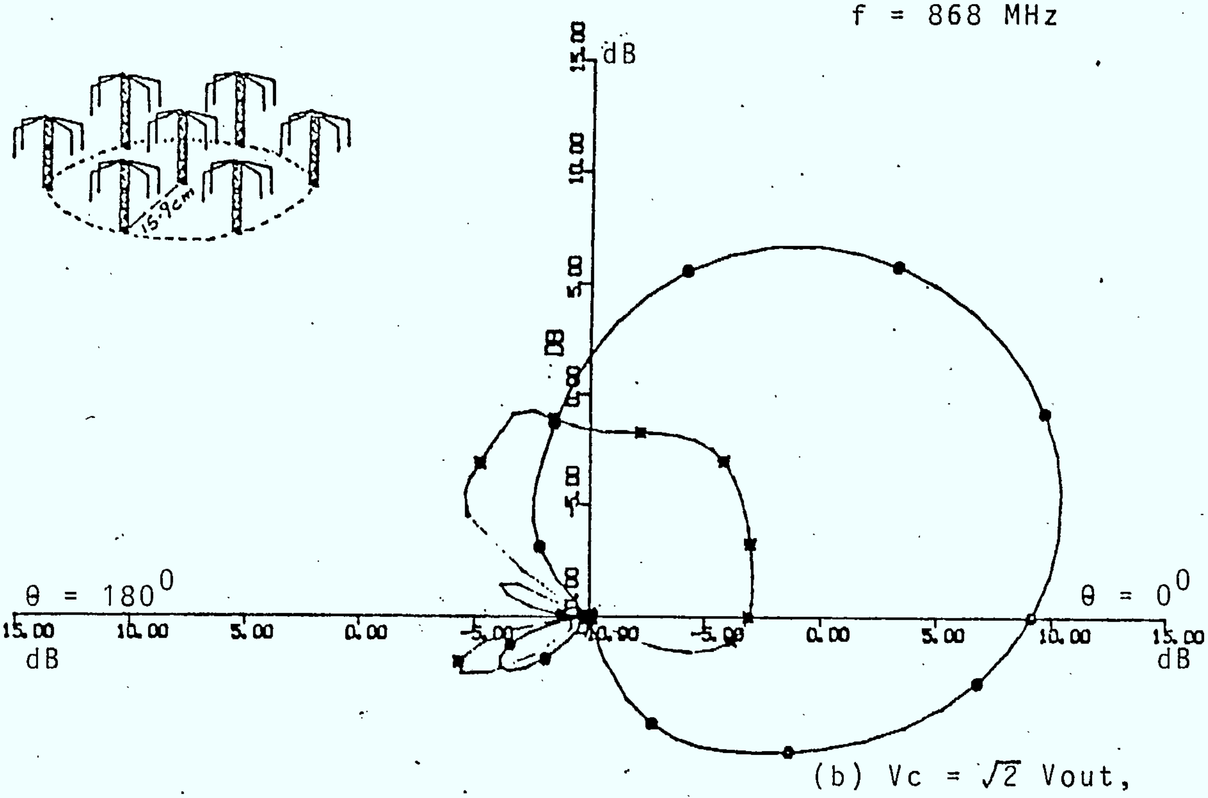


Figure 3.8 Canadian Marconi's mobile vehicular antenna elevation pattern for 7-element array



(a) Equal excitation,
f = 868 MHz



(b) Vc = $\sqrt{2}$ Vout,

Figure 3.9 Canadian Marconi's mobile vehicular antenna azimuth patterns

GAIN ASSESSMENTS

ITEM	MINIMUM dB	MEDIAN dB	MAXIMUM dB
ARRAY + ELEMENT GAIN *	12.6	12.8	13.0
ELEVATION PATTERN LOSS (to 20-40^0 El.)	-0.7	-0.4	0.0
PHASE SHIFTER LOSS (Inc. Phase error loss)	-1.2	-1.0	-0.8
POWER DIVIDER LOSS	-0.5	-0.4	-0.3
ELEMENT DISSIPATION LOSS	-0.2	-0.1	-0.1
AZIMUTH CROSSOVER LOSS	-0.3	-0.1	0.0
GROUND PLANE SCALLOPING EFFECTS	-0.4	0.0	+0.4
MUTUAL COUPLING EFFECTS	-0.5	-0.2	+0.3
RADOME LOSS	-0.3	-0.2	-0.1
TOTAL	+8.5	+10.4	+12.4

* Assumes 0.45 λ Spacing,
Element Height 18.0 cm.

CONCLUSION: GAIN WILL BE GREATER-THAN 9 dB for GREATER-THAN 99% OF COVERAGE VOLUME

GAIN WILL BE GREATER-THAN 10 dB for GREATER-THAN 90% OF COVERAGE VOLUME

Table 3.2 Canadian Marconi's gain assessment

3.4 COMDEV'S DESIGN

CRC has also given a contract to ComDev to investigate a UHF antenna system for a road vehicle applications. Their approach is, apparently, mechanically rotatable antennas, since they think any electronically scanned arrays suffer from excessive beam forming network losses, as well as cross over loss between beams. Among the rotatable antennas considered they felt the following three antennas are the suitable candidates;

i. Helix antennas
ii. Yagi-Uda arrays
iii. Patch antennas

The final recommendation was that a pair of helices, or a pair of crossed Yagi's array would be the best choice, although they leaned toward the latter one due to its switchable polarization capability. ComDev report does not address the effect of a finite ground plane on radiation and circuit properties of these antennas. Cubic corporation[1] has shown experimentally that the performance of a helix over a ground plane is unpredictable. They attributed the unexpected experimental results to a complex interaction of the helix with the ground plane.

ComDev does not provide any information on the radiation patterns of a helix or a pair of helices above a finite ground plane. In addition, the provided theoretical radiation pattern for a crossed Yagi array above an

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[1] "Trade-off between land vehicular antenna cost and gain for satellite Mobile Communication" report by Cubic Corporation (JPL contract 956691), August 1984.

infinite ground plane has been obtained by summing up the free space pattern of a titled crossed Yagi array with that of the image of the array in the infinite ground plane. That is, the mutual couplings between the arrays been neglected. Note that in their study, the boom of the array has been assumed 0.2λ above the ground plane. It is noted that the theoretical model used by ComDev is based on a crude approximation, and therefore it is expected that in their final report they would use a more elaborate model such as King's[1] Theory or the Method of Moment in order to predict the antenna characteristics. The method of moment is specially useful for theoretical analysis of the array above a finite ground plane, and there are already available a few computer programs which can tackle the problem.

Unfortunately in the ComDev report there is insufficient information on the mobile antenna electrical characteristics to report on.

3.5 COMPARISON

Among the recent R&D activities in Canada on vehicular antennas, CRC's design is the only one which has been built, tested, and gives a satisfactory performance. Based on CRC's design, a linearly polarized adaptive array with area size of about 50 cm in diameter, a receive gain of 8 dBic could be achieved at L-band which can be used for both Canadian and US applications. The 8 dBic gain takes into account the polarization loss due to change from linear to circular as well as the

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[1] R.W.P. King, "The Theory of Linear Antennas" Harvard University press, Cambridge, Massachusett, 1956.

duplexer loss. Note that for Canadian only applications, the diameter of the outer ring is about 25 cm.

Marconi's design is still at a theorectical stage, and if experimentally proven it will be an interesting design with good gain performance. For Marconi's circularly polarized phased array design (presently applicable only to the Canadian range of elevation) with the size of about 25 cm in diameter at L-band, the expected minimum receive gain is about 9 dBic. Doubling the diameter of the array to 50 cm could theoretically increase the peak gain to about 14 dBic, where 1 dB allowance for increased feed network as well as mutual coupling losses are assumed. Further, it is speculated that there would be about 1.5 dB loss due to extra pointing loss associated with narrowing of the beam, thus bringing the gain to a minimum of 12.5 dBic.

Therefore with reference to CRC's and Marconi's designs a practical range of G/T would seem to be from -13.5 dB/K to -18dB/K (assuming near 400 K system noise temperature).

ComDev's design could be the bulkiest of the three, as well as the most expensive one. Note that the ComDev's design is a mechanically rotatable antenna. That is, when signal is lost momentarily due to blockage, the system may not re-acquire the signal fast enough. This indicates the requirement for a gyro as well as a motor in order to minimize the outage. However, it seems that ComDev will have little problem in designing an L-band antenna with additional 5 dB gain to compensate in the differential free space loss between L-band and UHF.

4. DAMA PARAMETERS RELATED TO L-BAND SYSTEM CAPACITY

4.1 INTRODUCTION

This section examines DAMA system parameters in relation to L-band system user capacity and beam configurations. First the capacity of signalling channels for ALOHA and Slotted-ALOHA random access protocols are calculated and then a comparison of these protocols as well as that of Reservation-ALOHA is given.

It is shown that for specific beam topologies and certain boundaries in the system user capacity the required number of random access channels remain the same, under both ALOHA and Slotted-ALOHA schemes. This means that under such circumstances, the selection of a random access protocol should be based on other factors than their maximum network resource utilization namely, 18% and 36% for ALOHA and Slotted-ALOHA respectively. Applicable to this conclusion are plan 1 system traffic capacities of 6,000 users as well as Plan 2 capacity of 1,000 and 25,000 users if average access delays are between 1.0 and 1.5 second. For Plan 2 UHF system capacity of 35,000 users, Slotted-ALOHA requires a smaller number of access channels thereby utilizing the network resources more efficiently.

Note that these results are based on the simple concept of average access delay as a measure of performance and excludes the concepts of blocking probability associated with stabilization algorithms and considerations of cumulative distribution of the delay. Average access delay does not indicate the actual delay experienced by an individual user. Knowing its varience, the probability of larger than average delay can be obtained. Although a closed form of this varience is not simple to obtain, a computer simulation study might give a good estimate of the cumulative distribution of the actual delay experienced by the users.

Further, in section 5 of this report it is discussed that the provision of L-band capabilities with its dedicated beam coverage may affect the DAMA hardware and slightly increase its cost under the assumption of a multiprocessor architecture.

4.2 SIGNALLING CHANNELS AND RANDOM ACCESS PROTOCOLS

Signalling channels are overhead to the system. It is, therefore, a general design objective to keep their numbers as low as possible provided this reduction is not at the expense of unacceptable degradation in their expected performance. The governing protocol and user demand dictate the required number of access channels while access delay defines, to a large extent, the performance.

There are two types of signalling channels, namely, access channels and control channels. Access channels are used by the mobiles to send their call request to the DAMA Center and therefore a protocol is required to govern that access. For mobile applications call request duty cycle is very low so that fixed access assignments such as TDMA or polling protocols are very inefficient in terms of network capacity utilization or access delay and therefore these protocols are not suited for the MSAT application. In contrast random access protocols utilize the access channel very efficiently while maintaining acceptable average access delay. Three such protocols are considered for the MSAT application, namely, ALOHA, Slotted ALOHA and Reservation ALOHA which have been analyzed extensively in the literature and in the previous MSAT studies.

Control channels are used by the DAMA Center to respond to the mobile call request for the access channels and since the DAMA Center is the only station to transmit, no access protocol is required.

4.3 CALCULATION OF ACCESS AND CONTROL CHANNEL CAPACITIES

The signalling channel capacity is given by $K = S/\lambda\tau$ where:

S: is the throughput of the signalling protocol used, corresponding to a given average access delay.

λ: is the average number of call requests per second per user

τ: is the message length in seconds

Assuming that the mobile users (MRS and MTS) are statistically independent and each generates in the busy hour (according to poisson distribution) 0.0106 Erlang, the average number of call requests per second per user is 4.122×10^{-4}. This also assumes that the average call holding times are 20 sec. and 180 sec. for the MRS and MTS respectively and that 75% of the traffic is MRS and 25% of the traffic is MTS. Further, these signalling channels are assumed to have a bit rate of 2.4 kbps and that packet transmission time of 50 msec.

It is further assumed that call set-up/take down requires one packet for the access channels and three packets for the control channels.

For control channels, the DAMA Center is the only transmitting station, therefore the throughput is 100%, $\tau = 3 \times 0.05$ and $\lambda = 4.122 \times 10^{-4}$, hence

$K_{control}$ = 16,173 users per channel

For access channels, the throughput and capacities for two values of average delay are as follows:

average access delay = 1.0 seconds
S_{ALOHA} = .0923
$S_{S-ALOHA}$ = 0.1237
K_{ALOHA} = 4,4478 users per channel
$K_{S-ALOHA}$ = 6,001 users per channel

and

average access delay = 1.5 seconds
S_{ALOHA} = 0.1611
$S_{S-ALOHA}$ = 0.2554
K_{ALOHA} = 7,816 users per channel
$K_{S-ALOHA}$ = 12,391 users per channel

The required number of access channel versus number of users for plan 1 and plan 2 are shown in Figures 4.1, 4.2 and 4.3. Further, Table 4.1 clearly illustrates that for certain system capacities the required number of access channels remain the same under both ALOHA and Slotted-ALOHA schemes.

It should be mentioned that in calculating the signalling channel capacity we did not consider transmission errors which might arise from various sources such as fading, ignition noise, receiver noise and interference. These transmission errors may cause request or control packets to be lost which in turn will reduce the throughput and hence reduce the channel capacity. This problem was partially solved in the land mobile telephone by encoding each message using BCH Code and transmitting the encoded message several times, with the receiver applying BCH decoder and majority reception techniques.

However, recent studies done by Miller Communications Systems (July, 84 report) has shown that a (15,11) BCH block code satisfies the requirement of the MRS request channel. The approach taken in evaluating the error correction requirements of the request packet is to make the probability of incorrect decoding small relative to the probability of packet collision.

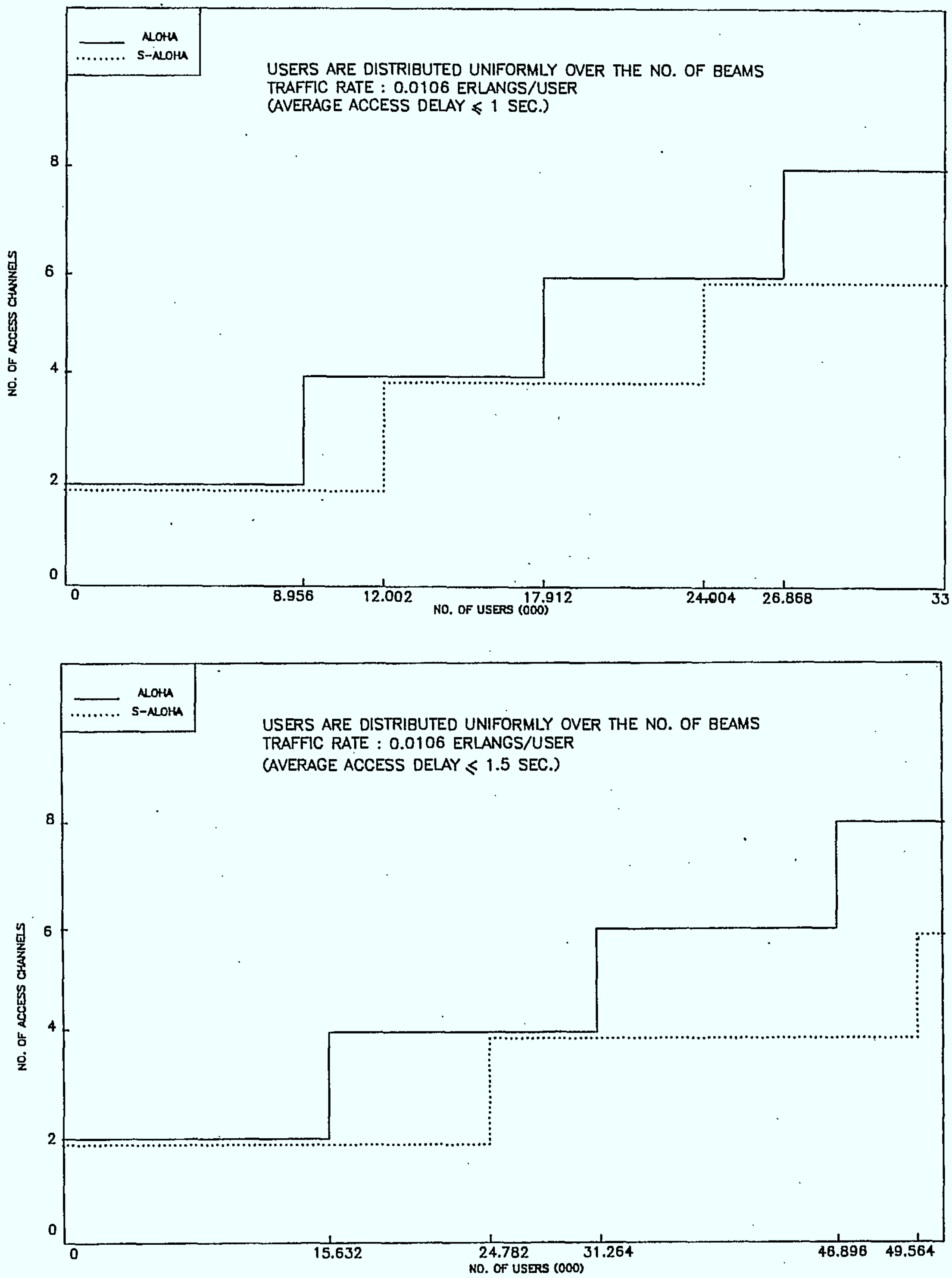


FIGURE 4.1 ACCESS CHANNEL REQUIREMENT FOR PLAN 1

2 L-BAND BEAMS

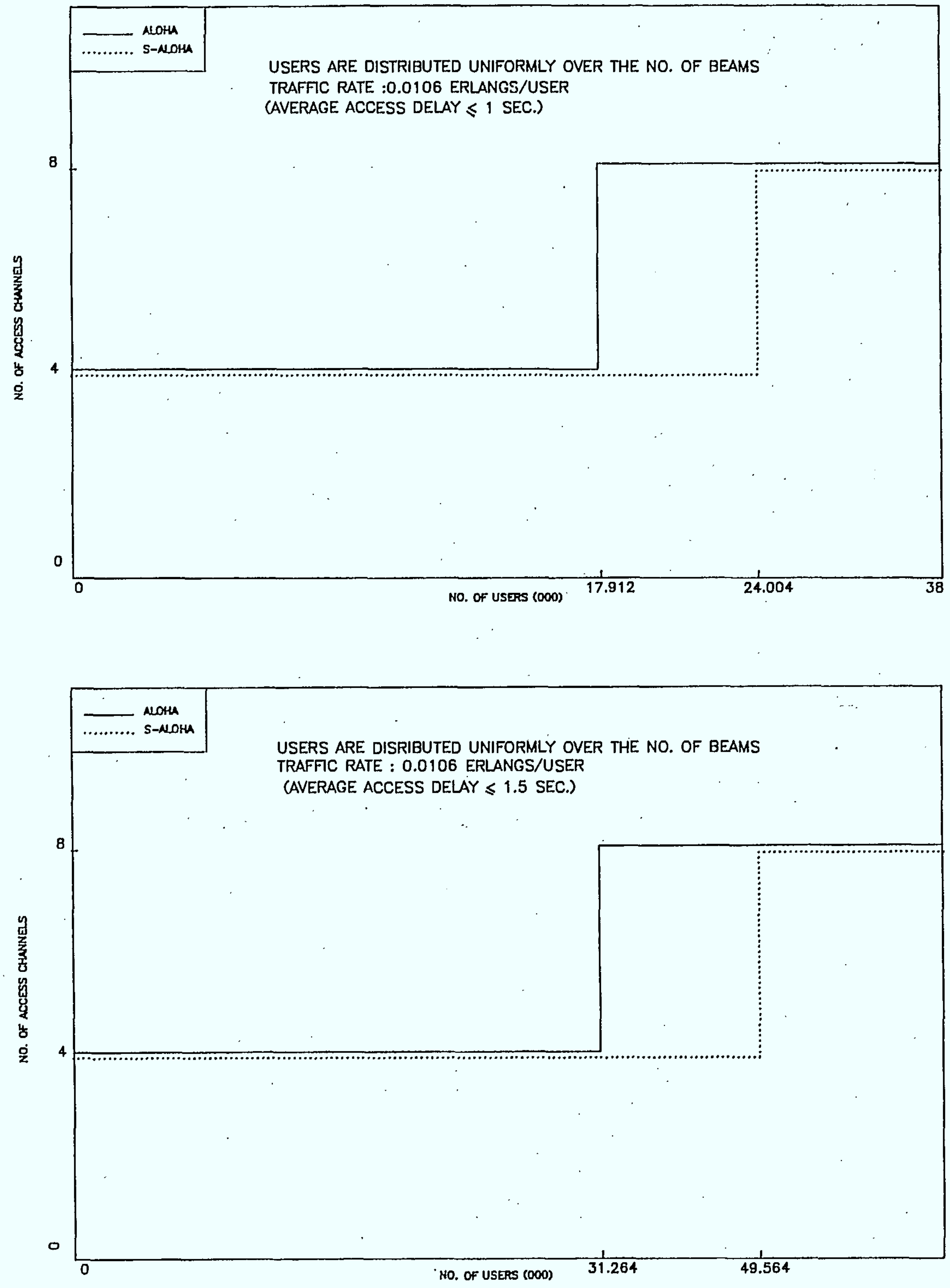


FIGURE 4.2 ACCESS CHANNEL REQUIREMENT FOR PLAN 1

4 L-BAND BEAMS

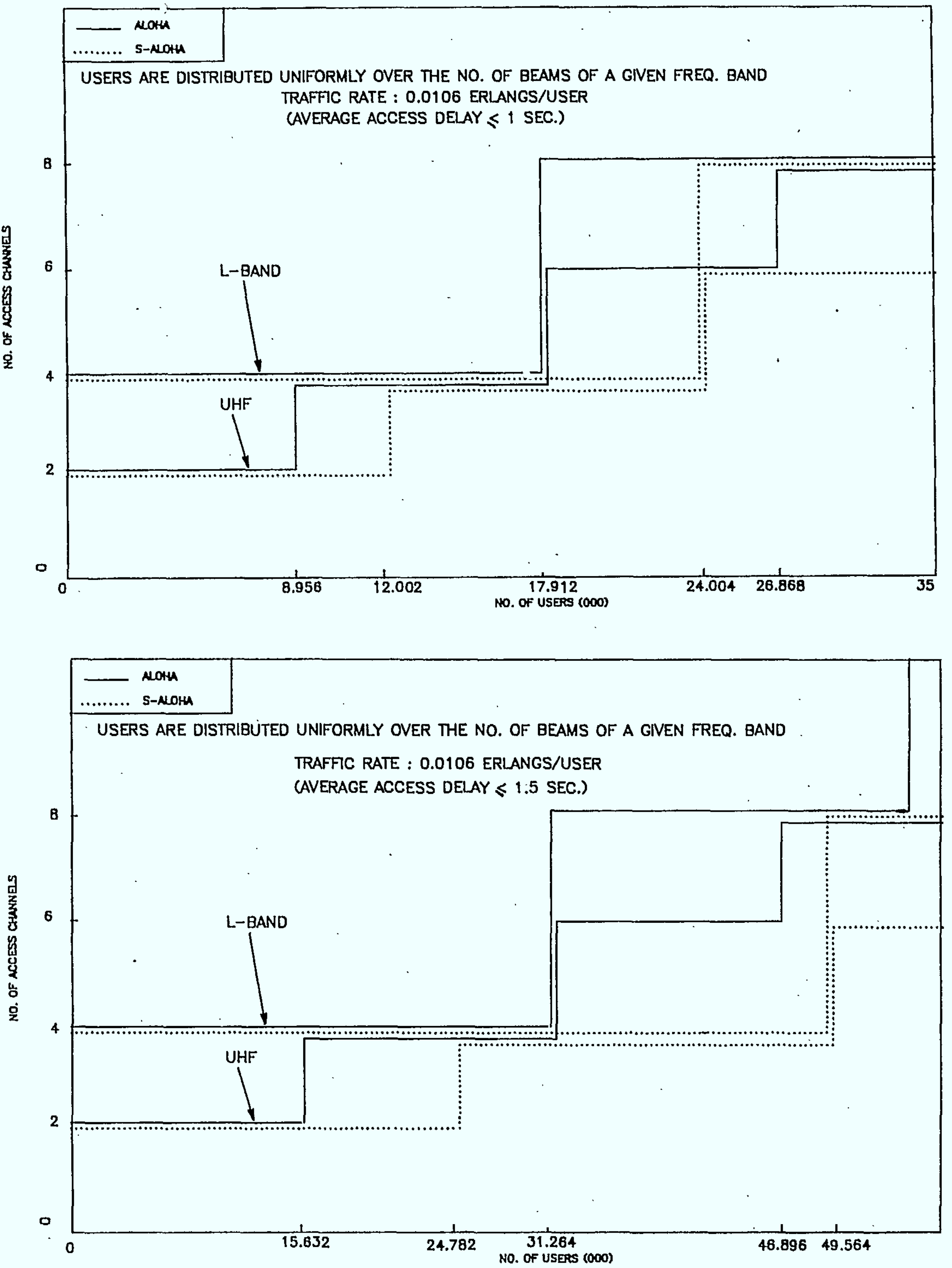


FIGURE 4.3 ACCESS CHANNEL REQUIREMENT FOR PLAN 2

2 UHF AND 4 L-BAND BEAMS

	UHF SYSTEM USER CAPACITY	L-BAND SYSTEM USER CAPACITY	NO. OF ACCESS CHANNELS REQUIRED			
			AVG. ACC. DELAY≤1 SEC.		AVG. ACC. DELAY≤1.5 SEC	
			ALOHA	S-ALOHA	ALOHA	S-ALOHA
PLAN-1	N/A	(a) : 6000	2	2	2	2
		(b) : 13000	4	4	2	2
		(c) : 20,500	8	4	4	4
PLAN-2	35000	——	8	6	6	4
		(d) : 1000	4	4	4	4
		(e) : 7000	4	4	4	4
		(f) : 25000	8	8	4	4

NOTE*:

(a) : PAM-D , 2 BEAMS , 32.3 dBw EIRP PER CARRIER
(b) : PAM-D2 , 2 BEAMS , 32.3 dBw EIRP PER CARRIER
(c) : PAM-D2 , 4 BEAMS , 32.3 dBw EIRP PER CARRIER
(d) : 0.235 STS SIZE SPACECRAFT , 10 YEARS , 32.5 dBw EIRP PER CARRIER
(e) : 0.235 STS SIZE SPACECRAFT , 10 YEARS , 28.5 dBw EIRP PER CARRIER
(f) : 0.27 STS SIZE SPACECRAFT , 10 YEARS , 28.5 dBw EIRP PER CARRIER

* Refer to Sub-task 1 report for details on system capacities

TABLE 4.1 COMPARISON OF THE REQUIRED NO. OF ACCESS CHANNELS

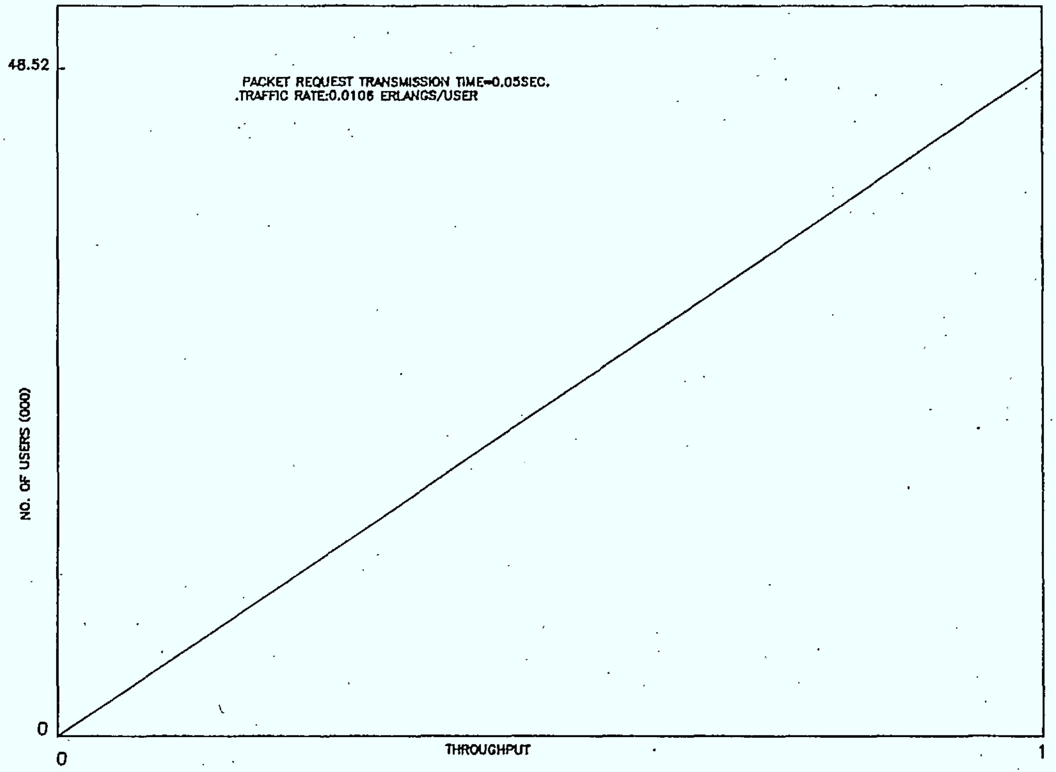
4.4 COMPARISON OF ALOHA, SLOTTED-ALOHA AND RESERVATION-ALOHA

The general behaviour of these protocols in terms of average delay versus throughput is shown in Figure 4.4. It is seen that much higher throughput can be achieved for Reservation-ALOHA at the expense of increased average delay in the low throughput region. The delay in the low throughput region consists of transmission delay and two round trip delays, namely, reservation packet delay and request packet delay. The dual structures of request is a fundamental aspect of Reservation-ALOHA where the request channel bandwidth is divided into two different slot structures. One is the full size slot which is used for collision-free transmission of standard request packets and the other is the small slot used to reserve full size slots. Therefore Reservation-ALOHA is suited for a system with a large number of users since a very high throughput could be achieved while maintaining an acceptable delay. In contrast ALOHA and Slotted-ALOHA protocols perform better in terms of a lower average access delay, for systems with relatively lower capacity.

However, there are other aspects to the performance criteria for random access protocols. It is well known that ALOHA and Slotted-ALOHA protocols are unstable. Lack of stability is due to statistical fluctuation of the traffic in the sense that the access channel(s) may drift into saturation. This means that channel becomes saturated due to collisions resulting in a zero throughput. There are several techniques for stabilizing these protocols in the literature. MCS simulation studies have shown that the normal Slotted-ALOHA can be made unconditionally stable if request packets are blocked after a certain number of attempts. MCS has simulated the delay performance of Slotted-ALOHA, in conjunction with a dynamic stability control algorithm. In this simulation study a performance goal was to keep the blocking probability for generating on-hook signals at 10^{-3} since the successful reception by the DAMA system of end of call message is critical.

Further, overall delay distribution could be a concern even if blocking probability and average delay criteria are met. Table 4.2 shows part of the delay distribution for Slotted-ALOHA obtained by MCS. Note, in particular, that although the average delay is approximately 1.3 seconds, the tails of the delay distribution is higher namely, the 90th percentile delay is 4 seconds, 99th percentile delay is 8-9 seconds. For Reservation ALOHA, although the average access delay is marginally poorer, the tails of the delay distribution is improved.

Another requirement with Reservation and Slotted-ALOHA is the uplink synchronization of the mobile terminals. In order to account for the wide range of possible user locations, the terminals must correctly position their own packet within the stated structure. By offsetting the timing of their transmissions with respect to the system reference, the terminals must ensure that uplink delays are compensated for, and all packets arrive at the satellite coincident with the intended slot. One method of handling this problem is to provide a large enough guard time within each slot such that the maximum differential from the nominal transmission delay will be accommodated. However, this technique will reduce the throughput capabilities and hence increase the average access delay. MCS has proposed a ranging burst organization scheme which provides the terminal with timing correction information every time it accesses the system. This will increase the amount of software required by the processors for call set-up/take-down as compared to ALOHA.



CAPACITY OF RANDOM ACCESS PROTOCOLS

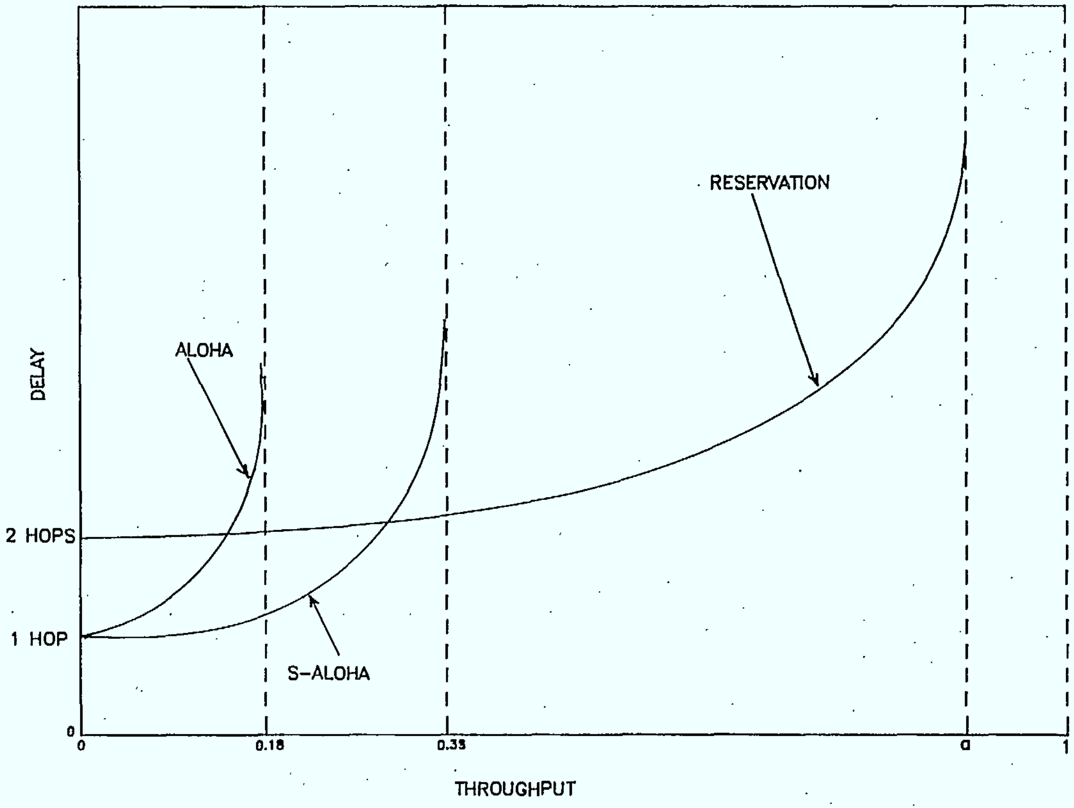


FIGURE 4.4 COMPARISON OF ALOHA , S-ALOHA AND RSERVATION ALOHA

Reservation ALOHA

Message Type	Blocking Probability	Average Delay (sec.)	90th Percentile Delay (sec.)	99th Percentile Delay (sec.)	Max. Delay (sec.)
New Requests[1]	3 x 10^{-3}	1.46	2.1	5.0	7.12
Off-hooks[1]	$\ll$ 1 x 10^{-3}	0.90	1.40	1.51	6.27
On-hooks	$\ll$ 1 x 10^{-3}	0.90	1.40	1.51	1.52

(1) Assuming 2 transmissions of the request packet are allowed before it is declared blocked.

S-ALOHA with dynamic stability control algorithm

Message Type	Blocking Probability	Average Delay (sec.)	90th Percentile Delay (sec.)	99th Percentile Delay (sec.)	Max. Delay (sec.)
New request[2] and off-hook[2]	7.83 x 10^{-3}	1.32	4	8	10
On-hook[3]	9.1 x 10^{-4}	1.35	4	9	10

(2) Assuming 5 transmissions before the packet is declared blocked.
(3) Assuming 7 transmissions before the packet is declared blocked.

Table 4.2 MCS CALCULATIONS OF DELAY STATISTICS

5. COST DISCUSSION

This section provides a qualitative assessment of changes in cost, for mobile terminals and DAMA system, which might occur as a result of the L-band utilization.

5.1 L-BAND MOBILE TERMINAL COST

5.1.1 L-BAND HPA COST

Some cost sensitivity studies for UHF and L-band mobile terminals have been done by General Electric company[1] and COMSAT Laboratories.[2] By building prototype L-band mobile terminals, researchers at General Electric conclude that there is little manufacturing cost difference between UHF and L-band mobile terminals when these terminals are produced in large quantities; however, no hard costing data were provided in this report.

W. Sandrin of COMSAT Laboratories identifies the power amplifier as the frequency sensitive cost component of the mobile terminal. Based on his survey of the literature and "informal cost estimates", he expects the L-band power amplifier to cost about 1.5 times more than the UHF-band counterpart of the same power rating. He assumes (based on "informal cost estimates") that 10- and 50-W amplifiers would cost approximately US $60 and US $300 respectively at UHF-band. Applying this cost

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(1) R.E. Anderson, "Satellite-Aided Mobile Communications Limited Operational Test in the Trucking Industry", Technical Report, General Electric Company, New York, 1980.

(2) W.A. Sandrin, "Land-Mobile Satellite Start-Up Systems", COMSAT TEchnical Review, Vol. 14, Spring 1984, pp. 137-164.

model and taking into account the increased power requirement (14.8W based on the assumptions of this Telesat L-band Study) and consequently higher power rating for L-band mobile terminals, it is expected that the incremental unit cost of L-band mobile terminals power amplifier would be about US $200.

Our own understanding of this subject, as was partly discussed in sub-section 1.4 of this report, also agrees with cost estimate of W. Sandrin of COMSAT. However, it should be noted that by referring to HPA we mean final stage transmitter design and its active element, the transistor in chip or modual form, rather than HPA as a separate unit with exotic box and gold platted connectors which could well exceed US $1000 mark at L-band. For example, recently TRW is advertising a 14W, Class-A linear transistor with ∞:1 VSWR at 1 GHz for $83 (U.S. dollars in 100s). This transistor satisfies the harshest professional operating conditions. It is expected that the commercial quality counterpart, if available, should cost much below the US $83. Now, taking into account the incremental complexity at 1.5 GHz, system requirements regarding linearity and power rating, the overall incremental cost of the final stage power amplifier design could be near the estimated US $200 for the L-Band system.

5.1.2 L-BAND ANTENNA COST

A linearly polarized phased array mobile antenna will have an increase in the required number of radiating elements by a factor of about 3 to 4 if the frequency of operation is changed from UHF to L-band and the design optimization is done over the same physical area size as its UHF counterpart. Further the number of beams in the azimuth plane to be handled by the beam steering computer will roughly double due to narrowing of the beam width. Taking into account the above factors as well as the break down of the estimated cost by Marconi as part of their recent studies on phased array antennas (Table 5.1), it would seem that the unit cost of a phased array antenna at L-band increases by a factor of 1.5. Assuming a cost of $1000 for the UHF antennas, the L-band version with a higher gain could cost more by an increment of about $500.

For linearly polarized mobile antennas (CRC design), there is only one driving element, power dividers and phase shifters are not required. Therefore, the unit cost of such an L-band mobile antenna with the same area size as its UHF counterpart is expected to be lower than the above mentioned increments. It should be noted, however, that this discussion is based on the assumption that the annual production rate remains the same for UHF and L-band designs. Most likely this assumption would prove to be the most important parameter dictating the actual cost.

5.2 IMPACT OF L-BAND ON DAMA SYSTEM COST

To determine the potential impact of either a stand alone L-band (Plan 1) or a hybrid UHF/L-band system (Plan 2) on the Central Control Station cost, we have briefly examined the DAMA system which is a major part of the CCS. As the system capacity is going to be different for the L-band, examination of the DAMA system was done with respect to the variation in the number of users as well as the beam configuration. In this context the following DAMA elements were briefly considered;

SUMMARY, 10,000/YEAR	MATERIAL	LABOUR	TOTAL
RADIATING ELEMENTS (QUANTITY 7)	27.16	33.18	60.34
MOTHERBOARD, PIN ELEMENTS ETC.	77.20	18.50	95.70
BEAM-STERRING COMPUTER	16.41	3.50	19.91
RADOME	7.50	------	7.50
BASE, CONNECTORS, ETC.	22.25	5.50	27.75
ASSEMBLY & TEST	------	17.72	17.72
TOOLING (AMORTIZED OVER 50,000 UNITS)	3.41	------	3.41
TOTAL LESS MARK-UPS, ETC.	153.93	78.40	232.33

Table 5.1 <u>Canadian Marconi's estimated Cost for antenna system $, Canadian</u>

- Hardware in terms of DP's and SP's and search processors.
- Software associated with search algorithms and data base organization.
- Software associated with random access signalling protocals

DAMA software is mostly dependent on call procedure algorithms and is not significantly sensitive to the number of users, however, DAMA hardware depends on the traffic statistics, namely nominal call arrival rate, average call holding time, etc. Variations in the number of users might be accommodated by increasing the number of DP's per beam and search processors if necessary and/or search algorithms and data base organization might have to be revised and replaced by either more or less sophisticated ones.

Dimensioning the DAMA hardware to reflect the above factors in relation to the lower system capacity associated with the L-band, although may prove to be insignificant, is a difficult task within the context of this study. However, the system user capacity associated with L-band lies within the limitations of the currently assumed processors. In our judgement the relative impact of the L-band system user capacity on DAMA hardware is insignificant.

It is only some of the specific beam configurations of the L-band which might slightly impact the DAMA hardware cost if a multiprocessor architecture is assumed. For Plan 1, which is 2 or 4 L-Band beams, CCS cost can be assumed to be almost the same as its UHF counterpart in the MSAT Business Proposal. For plan 2, which is 2 UHF and 4 L-band beams, CCS cost is expected to increase by roughly $3.2 M relative to the one in the Business Proposal, 2 UHF beams. This incremental cost which is 12% of total CCS cost, as shown in table 5.2, reflects the increase in the required DAMA hardware associated with the larger number of beams.

It should be noted, however, that it is not necessary for each beam to have a dedicated processor. For example, it is conceptually possible to have only 2 processors to handle the aggregated UHF and L-band traffic, provided the search algorithms, data base organization and the speed of the processors could handle the statistics, associated with aggregated rate.

PHASE I:	DAMA:	Hardware	$ 1,986 K	
		Software	$ 7,200 K	
	PSTN Interface Software:		$ 2,000 K	
	4 MTS Gateways Hardware:		$ 1,660 K	
	Network Management System:	Hardware	$ 192 K	
		Software	$ 2,000 K	
	S/System Unit Procurement, Manufacture and Test:		$ 7,202 K	(roughl
	S/System & Unit Design:		$ 997 K	
PHASE II:	Site Preparation:		$ 867 K	
PHASE III:	Installation:		$ 245 K	
	Contractors Basic Fee:		$ 2,512 K	
	Program Management & Support:		$ 1,848 K	
	TOTAL CCS COST		$28,70 K	(roughl

Table 5.2 Plan 2 CCS Cost Estimate Summary
(This reflects the increase in the required hardware)

6. CONCLUSION

The main impact of L-band utilization by MSAT on the ground segment is on the mobile terminals which are required to have higher transmit EIRP and receive G/T to compensate for the increased free space path loss and propagation attenuation at L-band. This applies only if the transmission performance is to remain the same as that for the UHF system, described in the Business Proposal.

Availability of L-band mobile terminals is currently limited to that of INMARSAT ship earth stations. The Inmarsat terminals, however, differ in specification with respect to both antenna performance and type of service.

Among the RF sub-systems of the mobile terminals affected by the change in the frequency are HPAs and antennas. In relation to HPAs there is a broad choice available at L-band, however, the designer of L-band mobile terminal HPAs is confronted with slightly stiffer constraints such as small dimension versus high power requirements. These factors are speculated to impact the cost by an increment of about $200 - $300 relative to the UHF version of a lower power rating.

In relation to antennas, simple azimuthally omni-directional antennas with a higher gain, to compensate for the increase in free space path loss between UHF and L-band frequencies, would result in a narrow beamwidth with large pointing loss that renders them impractical. The alternative is to keep the gain at nominal UHF levels with the penalty of an increase in the satellite EIRP per carrier.

Array antennas can provide acceptable transmit and receive gain performance with tolerable pointing loss. For a 70cm x 70cm microstrip phased array design considered in this study, the transmit and receive gain improvements relative to their UHF counterparts were 4.8 dB and 3.3 dB respectively. Such gain improvement still requires the satellite EIRP to be increased by about 5.7 dB and mobile transmit uplink EIRP by about 7.2 dB to obtain the same link quality as in the UHF. The latter would mean HPA power requirement of about 12 W. A phased array antenna of such higher gain is speculated to cost more by about $500 relative to its UHF counterpart.

From a practical design point of view, assessment of the recent R&D activities in Canada on mobile antennas shows that CRC's design is the only one which has been built and tested, and also gives a satisfactory performance. Based on CRC's design, a linearity polarized adaptive array with area size of about 50 cm in diameter (which can be used for both Canadian and U.S. range of elevation), a receive gain of about 8 dBic could be achieved. Marconi's design is still at a theoretical stage, and if experimentally proven it will be an interesting design with good gain performance. For Marconi's circularly polarized phased array design (presently applicable only to the Canadian range of elevation) with the area size of about 25 cm in diameter, the expected receive gain is about 9 dBic.

There seems to be no problem to design fixed, transportable, or field portable antennas with the required gain performance for L-band applications. Transportable services which exploit advantages of higher gain directional antennas and clear line of sight could provide acceptable performance and system availability, and are therefore, best suited for L-band.

Preliminary examination of DAMA parameters shows that for specific beam configurations and certain boundaries in the L-band system user capacity, the required number of random access channels remains the same, under both ALOHA and Slotted - ALOHA schemes. This means that under such circumstances, the selection of random access protocol should be based on factors other than the maximum network resource utilization namely, 18% and 36% for ALOHA and Slotted - ALOHA respectively. These other relevant factors could be tails of the cumulative distribution of the delay and adaptability to stabilization algorithms.